PRACTICAL RADIO TELEGRAPHY

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PREFACE

This book is written for radio students preparing to become radio operators. A thorough understanding of its contents will enable the reader to pass the theoretical examination given to applicants for a Radio Operator's License. It will also be useful to others not interested primarily in becoming operators but who want a knowledge of the theory and operation of Radio Telegraphy as used in the marine services.

The World War changed the trend in the design of radio telegraphic equipment from spark to vacuum tube and arc equipments. The change, which is still underway, rendered those text books written before the war obsolete in so far as modern equipment is concerned.

With the advent of broadcasting, immediately after the war, came scores of radio books nearly all of which neglected entirely practical explanations of radio telegraphic apparatus. The authors of this book being engaged in the training of radio operators keenly realized the need for a reliable, adequate and well-balanced text and set about gathering material for this volume.

The arrangement of chapters is such that, in all but three or four of the advanced chapters on transmitting equipments, a student or teacher may cover one chapter as one assignment. As a further aid a series of examination questions appear at the end of each chapter.

Many text books on radio telegraphy require that the reader be versed in elementary electricity, mathematics and chemistry. This book does not require these prerequisites. It starts with an explanation of elementary electricity and gradually builds on this knowledge until radio circuits and apparatus are understandable.

It is hoped that this book will serve the two-fold purpose of training radio operators and of being useful as a general handbook for those having to use and care for the types of equipments it describes.

THE AUTHORS.

NEW YORK, N. Y.
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Dubilier Condenser Corporation
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and to their many radio operating and engineering friends who offered helpful suggestions and to the Institute of Radio Engineers for permission to reproduce the symbols which appear in the Appendix.

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PRACTICAL RADIO TELEGRAPHY

CHAPTER I

MAGNETISM

Natural Magnets.—The name "magnet" was first applied to brown-colored stones which possessed the peculiar property of attracting small pieces of iron or steel. Later, it was found that if a piece of this stone was suspended freely by a string it possessed the now very important property of pointing in a particular direction, very nearly north and south. It received the name of "lodestone" or "leading stone" due to this directional effect. In technical terms this stone is referred to as magnetic oxide of iron or magnetite. The magnetic properties or attractive forces seem to be centered at two or more points on the stone, while at other points no magnetic force is evident. It is called a natural magnet because it is found to be magnetic in its natural state, and a lodestone because it possesses the remarkable property referred to which caused it to be used for navigation.

Artificial Magnets.—If a piece of iron or steel is rubbed by a piece of lodestone, the former will then have the magnetic property of attraction. The piece of iron or steel is then termed an artificial magnet. The process by which this property was acquired is called "magnetization," and the steel or iron is said to be magnetized. It is not possible to create enough magnetization with a lodestone to make it powerful enough for commercial uses.

Poles of a Magnet.—The ends of a magnet are termed its poles. The end which points to the north geographical pole is generally called the *north seeking pole,* and is usually marked on one end of the magnet by an N while the other end is called the *south seeking pole* and is marked S.

The term "magnetic polarity" refers to the nature of the magnetism at a particular point on the magnet, or in other words, whether it is an N or an S seeking magnetism.

Magnetic Attraction and Repulsion.—If a steel bar which has been magnetized is suspended at the center by a silk thread and placed in the vicinity of a north or a south magnetic pole it will tend to swing parallel with the magnetic field created by the pole.

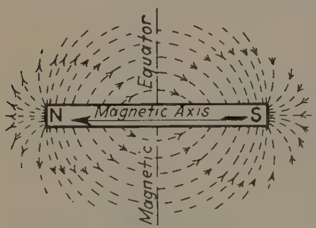


Fig. 1.—Magnetic field about a bar magnet.

Figure 1 illustrates the magnetic lines of force emanating from the *north* pole and entering at the *south* pole through the air medium. The lines of force then return to the *north* through the magnet, thus completing its field.

If the bar is carefully marked at one end for reference, it will be noted that one particular end will always point in a definite direction. This is due to the polarity effect of one magnetic field upon another. No matter how many times the bar is turned by hand it will always return to its original magnetic position. Figures 2*a* and 2*b* illustrate the magnetic effect

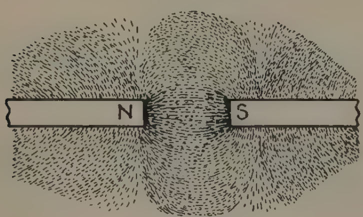


Fig. 2*a*.—Magnetic attraction between two unlike poles.

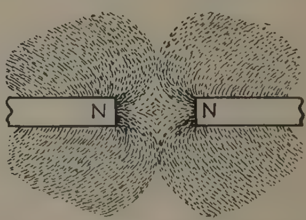


Fig. 2*b*.—Magnetic repulsion between two like poles.

of two magnetic fields, one upon the other. Figure 2*a* shows how the lines of force tend to combine and thus attract the two bodies, while Fig. 2*b* shows the "bucking" or repelling effect of the fields and, hence, a repulsion of the two bodies. This holds true with all magnetic bodies. Whenever two *north* poles or two *south* poles are placed near each other they will tend to repel one another. On the other hand, if poles of *north* and *south* polarity

are placed in the same vicinity they will attract due to the combining effect of the magnetic fields. The law governing this action is stated, *liked poles repel; unlike poles attract.*

Magnetic Fields.—Various forms of magnetic bodies possess certain magnetic advantages. Of these the two most important are the bar magnet and the horseshoe magnet.

Figure 3 illustrates the magnetic field arrangement of a horseshoe magnet. Compare this with the field arrangement of the bar magnet in Fig. 1. Note that the concentration of the lines of force in Fig. 3 is much greater than in Fig. 1. This is obviously due to the shorter air path through which the lines of force travel, and hence results in a lower amount of magnetic leakage. Therefore the strength of the magnetic field at the poles of a horseshoe magnet would be considerably stronger than that of a bar magnet.

FIG. 3.—A horseshoe magnet.

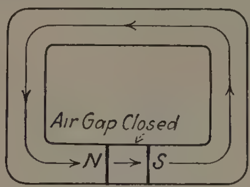


FIG. 4.—Magnetic lines of force in a closed core.

If it is desired, however, to decrease the magnetic leakage of the horseshoe to a still lower degree, then a small iron bar may be placed directly across or between the poles as illustrated in Fig. 4.

Whenever this is desired the magnetic material may be formed into a closed magnetic path by arranging it into a horseshoe, square, circular or rectangular form.

Magnetic Transparency.—If a magnet were placed in a position to deflect a magnetic needle and if a non-magnetic substance, such as glass, wood, brass, or rubber were placed between the needle and the magnet, the lines of force would complete their circuit through the non-magnetic body, as shown in Fig. 5. If a piece of iron were interposed between the magnet and the needle, however, the iron would act as a *magnetic screen* and reduce the needle deflection towards the magnet (Fig. 6).

A compass needle if placed in the center of a thick iron case would be entirely screened from any external magnetism.

Specific Magnetic Effects of Iron and Steel.—The magnetic properties of iron and steel are divided into two groups:

1. Permeability.
2. Retentivity.

Each one of the above metals, though magnetic, possesses properties to which are due careful consideration.

If a piece of iron is placed under the influence of a strong magnetic field, it will become magnetized almost instantly. The steel, however, will not allow itself to become as easily magnetized, but when magnetized it will retain its magnetism for an almost indefinite period, while the iron will lose practically all its magnetism once it is removed from the magnetic influence. It is thus apparent that iron possesses a factor of becoming more easily magnetized, or in other words allows the magnetism to pass through it more readily. This is called "magnetic permeability." The reason for this phenomenon can be readily seen by comparing the physical structures of both metals.

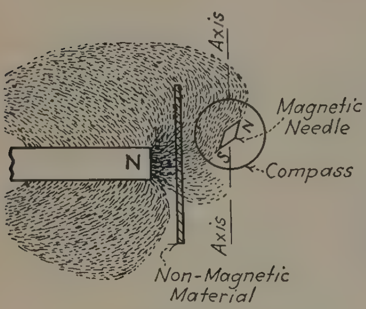


FIG. 5.—Magnetic transparency.

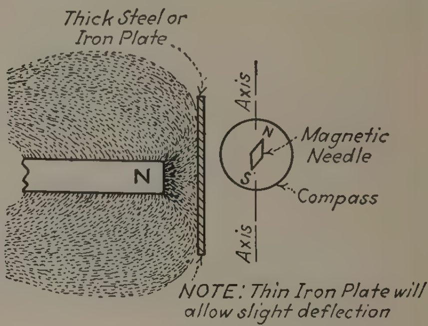


FIG. 6.—Magnetic screen.

Theory of Magnetism.—The theory of magnetism is based on the law of matter, which states that all bodies which have weight, as gases, liquids, and solids, are composed of minute particles known as "atoms." It is possible by means of chemical or electrical reactions to create a combining effect of certain types of atoms. When this takes place the resultant combination forms into a mass, or body, and is called a "molecule."

For example, water has weight due to its atomic structure. It consists of a combination of hydrogen and oxygen atoms of definite proportions as follows: 2 parts of hydrogen and 1 part of oxygen, referred to as two hydrogen atoms combining with one oxygen atom. If these two minute bodies join forming a single unit we may apply a name to that unit; a molecule of water.

The molecule is, therefore, a minute particle of weight made up of different atoms to form a specific material.

Steel and iron are composed of their respective molecules, both of which are or may be effected by magnetic influence. It is assumed that the bar of steel in its unmagnetized state has its molecules arranged in a promiscuous fashion, as in Fig. 7.

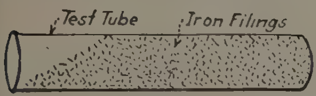


FIG. 7.—Hypothetical arrangement of molecules in an unmagnetized body.

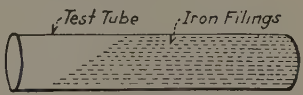


FIG. 8.—Hypothetical arrangement of molecules in a magnetized body.

If the steel bar is stroked with a magnet or placed in the magnetic field of a current-carrying circuit in which the current is unvarying, then the molecules will arrange themselves according to the law of attraction, that is, each of the molecules will arrange itself symmetrically with the axis of the bar, acting upon one another and so tending to form a series of little magnets, and, consequently, producing an external magnetic field about the bar. The molecular arrangement would then be as in Fig. 8.

The same procedure would also apply to the iron. The molecules in the steel cannot be as readily straightened, however, due to the greater density of the molecules in the steel. This would necessitate a greater magnetizing power, but once the molecules are all straightened they would not be as liable to fall into their original distorted condition and therefore the steel will have a greater tendency to retain its magnetism after the magnetizing influence has been removed. Hence, the term "retentivity" is applied to all steel magnets.

On the other hand, the molecules in the iron, especially soft iron, will straighten out much more rapidly when under the influ-

ence of a magnetic field, but they will fall back again just as readily to their original distorted position when the magnetic field is removed. This is due to the lack of the molecular density in iron, especially soft iron. Thus the iron will retain only a very small fraction of its magnetic power when it is removed from its magnetizing influence. This small amount of magnetism still remaining in the iron is called its "residual magnetism."

Questions

1. What is a natural magnet?
2. What metals are used for artificial magnets?
3. What is meant by the term permeability?
4. What is meant by the term retentivity?
5. Under what conditions will magnetic fields repel?
6. What is meant by the term magnetic transparency?
7. How can the magnetic leakage in a horseshoe magnet be minimized?
8. What material is best suited for permanent magnets?
9. What is meant by residual magnetism?
10. Describe the theory of magnetism.

CHAPTER II

ELEMENTARY ELECTRICITY; BASIC PRINCIPLES

Atoms and Electrons.—In the previous chapter the brief theory of molecular structure has demonstrated how certain atoms of different elements might be combined to form a certain type of molecule. In a like manner the two atoms of hydrogen and the one atom of oxygen can also be separated from each other by chemical and electrical methods.

An atom is found to be a sort of solar system, with a sun and planets: the empty regions between the sun and the planets fill up more space than they do, so that much the greater part of the volume that seems to us to be filled by a solid body is in reality unoccupied. In the solar system we might refer to the planets as "electrons" and the sun as the "nucleus." Similarly, in all bodies which possess weight, *i.e.* gases, liquids and solids, there is evidence of nuclei and electrons. It thus seems quite logical according to scientific research, that the weight of a body is dependent upon its atomic structure and, in its turn, the activity in or outside of the atoms is dependent upon the number of electrons around their nuclei.

When an atom has many electrons, it seems that they are arranged in successive rings around the nucleus, all revolving around it in either ellipses or circles. The chemical or electrical properties of the atom depend almost entirely, upon the outer ring.

The simplest atom is that of hydrogen, which has a simple nucleus and a single electron. The most complex atom known is that of uranium, which has, in its normal state, 92 electrons revolving around the nucleus. It is very possible that atoms of a still more complex nature may be discovered some day.

When an atom is referred to as a "neutral atom" it simply means that it contains the original number of electrons attached to it. If, on the contrary, the atom loses one or more of its elec-

trons it no longer possesses its neutral state and is said to be in a state of electrification.

Electricity and Electrical Strain.—The atom may thus be electrically analyzed as creating a state of behavior under certain conditions. For example, assume a piece of ebonite and one of fur with their atoms in a neutral state. If the two materials are rubbed so as to create intense friction some of the atoms will be disturbed, and electrons torn out of some in such a manner that, after the rubbing, a number of free electrons, independent of atoms, are found on the ebonite, and a number of the atoms of fur which have not their proper number of electrons remain in the fur. This will leave some of the fur atoms with a deficit of electrons, or in an unbalanced state. If, therefore, some light body, as paper, is brought into the vicinity of the fur it would be attracted to it in the effort to again restore to it the electrons which have been lost. This is called electrification due to the friction of two dissimilar materials. It can readily be seen that certain bodies when excited will produce a state of strain in their vicinity. Experiment proves that a body on which free electrons are placed has the effect of what is called a negatively charged body, and a body robbed of some of its electrons acts as a positively charged body.

In other words, whenever electrons, which are "negative" particles of electricity, are taken from their balancing medium, the nucleus, they will leave the latter in an opposite state of behavior which is called "positive." Positive and negative charges are, therefore, simple terms for expressing behavior.

Potential.—When a body is charged either positively or negatively it is said to have a positive (+) or negative (−) pressure. When water is put into a tank, there is always a certain pressure of water in the tank which can be measured by the height of the water.

If two tanks are connected with a pipe and one tank has a greater height of water than the other, that is, if the water pressure in one is greater than in the other, then the first would have a positive pressure with regard to the second, and the second a negative pressure with respect to the first.

Electricity is analogous to these effects, but instead of using the word "pressure" the word "potential" is used. This will

be clearly seen if a tank on a level higher than the sea is compared with an electrical potential. The tank in the above example would have a positive potential with respect to the sea, and, similarly, a positively electrified body would have a positive potential electrically; a body with negative electrification is analogous to a tank in which the level of the tank is below the sea level. Whenever therefore, there is a difference of potential between two bodies electricity will flow from the one to the other if the two are connected by a conducting medium, exactly the same as water will flow from one tank to another.

Similarly, generator wires of different potentials would produce a flow of current through a conductor. Again, the same action can be produced in two dissimilar wires, for example, such materials as copper and iron. Each wire possesses a difference of potential when they are joined and subjected to heat.

Here the heat creates an excitation of the atoms in the wire which results in a flow of current when the free ends of the wires are connected.

ELECTROMOTIVE FORCE—CURRENT—RESISTANCE

Electrical Currents.—Whenever a flow of current in an electrical circuit is present it is spoken of as a "movement of electrons" from one point of the circuit to another and in conventional terms is simply referred to it as a flow of electricity. In the practical phase of electricity there will arise no necessity for analyzing complex atomic structures such as are found in the various elements, but a sound understanding of the principles is needed so that they may be applied to standard electrical circuits and apparatus.

Electromotive Force.—In order to maintain a steady flow of current in an electrical circuit, there must be a constant pressure and a suitable path through which the current may flow. The pressure in electrical circuits is called the "electromotive force," or e.m.f. In hydraulic systems the pressure is referred to as a certain number of units or pounds per sq. inch; electrically this is the "volt" and is used to express difference of potential or electromotive force. Hence, when the voltage of a battery or generator is mentioned, the reference is to its pressure as having a certain number of volts.

Current Strength and Quantity.—The rate of flow of water through a pipe is measured as so many gallons a second, which expression includes a definite quantity of water and a unit of time. The distinction between the terms "rate of flow" (strength) and quantity must be carefully understood in order to comprehend the practical application of these terms to electrical circuits. For example, at the rate of 1 gal. of water a second there might be 3,600 gal. of water delivered to a tank in an hour, thus distinguishing the rate of flow from the quantity and naming it. Electrical quantity is measured in "coulombs." In referring to the relation between quantity and rate of flow in an electrical circuit, the electrical term for rate of flow or strength must be used. This unit is called the "ampere." When one practical unit of quantity of electricity (coulomb) flows continuously every second, the *rate* of flow or the *strength* is said to be 1 amp., or if 2 coulombs flow continuously every second, the strength of the current would be 2 amp., and so on. Hence, it can be readily seen that the current in amperes is independent of the length of time the current flows in a given circuit, regardless of whether it flows for a fraction of a second or for hours.

To find the total quantity of current flowing through a circuit in a given time:

Multiply the amperes by the time (in seconds),
in which I = current strength in amperes.
Q = the total quantity expressed in coulombs.
T = Time the current flows (seconds).

Then

Quantity = current strength × time or in
coulombs = amperes × seconds.

$$Q = I \times T.$$

Example 1.—If an incandescent lamp requires a current of ¼ amp. to maintain a steady brilliancy, what quantity of electricity would be consumed if the lamp is lighted 2 hr.?

$$2 \text{ hr.} = 60 \times 60 \times 2 = 7{,}200 \text{ sec.}$$
$$\text{Formula } Q = I \times t = \tfrac{1}{4} \times 7{,}200.$$
$$Q = 1{,}800 \text{ coulombs.}$$

To find the average current strength (in amperes) when the quantity and the time are known:

$$I = \frac{Q}{t}.$$

Proving Example 1:

$$Q = 1{,}800 \text{ coulombs.}$$
$$t = 7{,}200 \text{ sec.}$$
$$I = \frac{1{,}800}{7{,}200}.$$
$$= 0.25 \text{ or } \tfrac{1}{4} \text{ amp.}$$

To find the time (in seconds) required for a given quantity of electricity (in coulombs) to pass a certain point of a circuit:

$$t = \frac{Q}{I}$$

Proving Example 1:

$$Q = 1{,}800 \text{ coulombs.}$$
$$I = \tfrac{1}{4} \text{ amp.}$$
$$t = \frac{1{,}800}{\tfrac{1}{4}}.$$
$$= 7{,}200 \text{ sec.}$$

Electrical Resistance.—When water flows through a pipe, the resistance it meets with depends directly on the length of the pipe, its diameter and general conditions, such as bends, roughness, etc. Similarly, when a difference of potential is applied to an electrical circuit, a current flows through the circuit, and the amount of opposition (resistance) offered to the flow is proportional to the resistivity of the wire, which in turn depends upon the character of the material through which the current flows, its length, diameter, and temperature. The character of the materials which make up the circuit is the most important consideration, for different materials allow electrons to pass along them at different rates.

The resistance effects of different materials are determined by certain experiments and calculations and are called their "specific resistances."

The following table shows the specific resistance of a few materials as compared with pure copper, assuming the copper to have a unit of one:

Silver, pure annealed	0.925
Copper, annealed	1.000
Copper, hard-drawn	1.022
Aluminum (97.5 per cent pure)	1.672
Zinc (very pure)	3.608

Brass	4.515
Phosphor-bronze	5.319
Iron wire	6.173
Nickel	7.726
Steel (wire)	8.621
German silver	17.300

An examination of the above table shows that the specific resistance of alloys is very much greater than that of the pure metals. This is a characteristic property of alloys, which is taken advantage of in the preparation of wires of high specific resistance. Even a slight trace of another metal, which by itself may be a good conductor, has an enormous effect on the resistance, hence, copper used for electrical purposes has to be exceptionally pure.

The specific resistance for many practical purposes is expressed in *ohms*. (The electrical sign for the ohm is usually shown thus Ω.) This is the common term used in expressing the resistance in an electrical circuit in ohms per cross-sectional unit. For example, the resistance of 1,000 ft. of copper wire which has a diameter of $\frac{1}{10}$ in. (No. 10 B. & S. gage) is about 1 ohm, although a piece of iron wire of the same length and cross-section has a resistance of about 6 ohms, and a similar piece of German silver wire has a resistance of about 17 ohms. Raising the temperature has the effect of increasing the resistance; lowering the temperature decreases the resistance. A wire, therefore, which has a resistance of 6 ohms at 30°C. will have a higher resistance if the temperature is higher, and vice versa.

Ohm's Law.—In any circuit through which there is a flow of current we must obviously have all of the three following factors present: (1) the *pressure* or *potential difference* (volts) which causes the current to flow; (2) the opposition or "resistance" (ohms) which must be overcome to produce a current flow; (3) the *current strength* (amperes) which can be maintained in a circuit as a result of the pressure overcoming the resistance and thus causing a flow. In any circuit there is always a definite relation between these three units and, therefore, the value of any one unknown factor may be calculated when the values of the other two are known. The law governing these calculations is known as Ohm's law.

RULE 1.—The current strength in any circuit is equal to the electromotive force applied to the circuit, divided by the resistance of the circuit.

$$\text{Current} = \frac{\text{pressure}}{\text{resistance}}$$

or

$$I = \frac{E}{R}.$$

Example.—If a vacuum tube having a resistance of 55 ohms is connected across a potential of 110 volts what current will flow through the tube?

$$I = \frac{E}{R} = \frac{110}{55}.$$
$$I = 2 \text{ amp.}$$

The current strength in any circuit increases or decreases directly with the increase or decrease in the potential, when the resistance in the circuit is assumed to be constant. If the pressure is constant, the current will increase as the resistance is decreased and decrease as the resistance is increased.

In other words the current might be said to vary directly with the e.m.f. and inversely as to the resistance.

Example.—If in the above problem the voltage is increased to 220 volts how many amperes will flow through the tube?

$$I = \frac{E}{R} = \frac{220}{55}.$$
$$I = 4 \text{ amp.}$$

RULE 2.—The amount of electromotive force required to maintain a certain current strength in a circuit in which the resistance is known, is equal to the product of the current strength and the resistance

$$\text{Pressure} = \text{current} \times \text{resistance},$$

or

$$E = I \times R \text{ (written } IR\text{)}.$$

Example.—How much pressure must be applied to a circuit to cause 5 amp. to flow if the resistance is 30 ohms?

$$E = I \times R = 5 \times 30.$$
$$E = 150 \text{ volts.}$$

The pressure varies directly with the current and resistance values. For example, if it is desired to send a greater current through the same resistance, a greater amount of pressure must be applied to the circuit, or if the same current is to be passed through a greater resistance, then a greater pressure must be applied.

RULE 3.—To find the value of resistance required to be inserted in any circuit, so that a given current will flow under a known pressure: the resistance is equal to the pressure to be applied, divided by the current strength that is to be maintained.

$$\text{Resistance} = \frac{\text{pressure}}{\text{current}}.$$

or

$$R = \frac{E}{I}.$$

Example.—A certain resistance passes a current of 7 amp. through a circuit at a pressure of 35 volts. What is the value of the resistance?

$$R = \frac{E}{I} = \frac{35}{7}.$$

$$R = 5 \text{ ohms.}$$

When a constant pressure is desired its resistance must be cut in half if the current is to be doubled, or, if there is to be a constant current maintained in which the pressure is doubled, then the resistance must also be doubled.

A simple method of remembering the Ohm's law application to direct-current measurements is illustrated in Fig. 9.

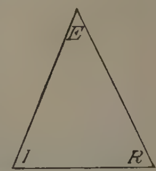


FIG. 9.—Ohm's law.

For example, if the voltage and amperage in an electrical circuit is known, the pyramid diagram may be applied as follows: Place the finger over the unknown quantity, *i.e.*: the resistance R. This leaves the remaining letters E and I for the voltage and current, respectively. Thus the letter E being above the letter I simply means that the current I is divided into the voltage E to give R. If the voltage, for example, was found to have been 100 volts and the current 2 amp., then by the application of the pyramid explanation, the resistance must be 50 ohms.

Similarly, if it is desirable to find the current I if the voltage E and the resistance R are known, then by the same application the current can be determined by placing the finger over the unknown quantity I. For example, if the voltage E is 100 volts and the resistance R is 50 ohms, then, by application of the pyramid, it will be found that the current I will be 2 amp. Similarly, if the resistance R in an electrical circuit is 50 ohms and the current I 2 amp. then by application of the pyramid the unknown quantity E can be determined by placing the finger over the E. Thus multiplying IR we will find the voltage E to be 100.

Simple Electrical Circuits.—Ohm's law shows that, for a given voltage, the lower the resistance the larger will be the current, and the higher the resistance the smaller the current.

Circuits are divided into three classes, which are:

1. Series circuits.
2. Parallel circuits.
3. Series-parallel or parallel-series circuits.

Series Circuits.—Figure 10 shows a simple series circuit in which may flow a steady current. This is called a series circuit because the current flows in one continuous path. Furthermore,

this current is the same at any point in the circuit. An ammeter placed at any point would give the same reading. The ammeter is a device for measuring current strength in amperes.

Now, as each of these parts will have resistance, each will have what is known as an *IR* drop, which is always directly proportional to the resistance. Hence, each *IR* drop represents a certain amount of e.m.f. expenditure in each part of the circuit, and the differences of potential produced by the source must equal the total e.m.f. expended. In other words, the input must equal the output plus losses. This can be readily seen if the three parts used in all series circuits are considered.

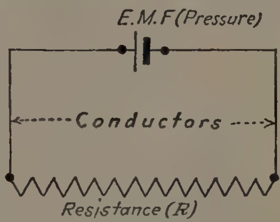


FIG. 10.—A simple-series circuit.

1. The inside or internal part of the e.m.f. source, *i.e.* batteries, generators, etc.

2. The leads which connect the apparatus to the source, *i.e.* lines.

3. The apparatus itself.

Thus, if each one of these parts has a certain amount of resistance and the same current is flowing through them, each will have an *IR* drop which is proportional to its resistance. Therefore the *IR* drop in the source is called the "internal drop" and that in the line is called the "line drop." Hence, since each *IR* drop represents an expenditure of e.m.f., then the total expenditure of e.m.f. in the circuit will be the sum of the e.m.fs. expended in each part and, obviously, the difference of potential produced by the source must equal the total e.m.f. expended. Therefore, the supply e.m.f. must always supply a higher voltage than is required at the source terminals. The source voltage is referred to as a definite "no-load" voltage when no current is being delivered to the external circuit, and as "load" voltage whenever current is being forced through the circuit. Obviously, there will be a certain voltage drop whenever current is drawn from a source, the amount, of course, being proportional to the resistance of the circuit.

It is seen, therefore, that any source of e.m.f. having a high internal resistance will not permit a large current to flow in the external circuit, because even a small current will cause an inter-

nal expenditure of voltage equal to the total voltage of the source and, therefore, no voltage will be available at the terminals for external use.

Figure 11 shows a series circuit with more than one resistance unit connected in series. Remembering that the same amount of current passes through every part of the circuit, then the total e.m.f. will be the sum of all the IR drops. Thus, the equivalent resistance (a resistance having a total value of the three) in a series circuit is equal to the sum of the resistances of the individual units (assuming the wires to have a negligible resistance) thus

$$R_1 + R_2 + R_3 = \text{Total Effective Resistance}$$

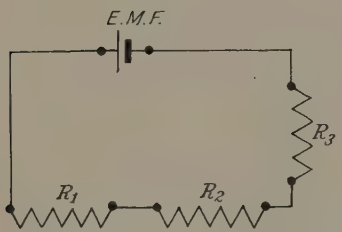


FIG. 11.—A series circuit with three resistances.

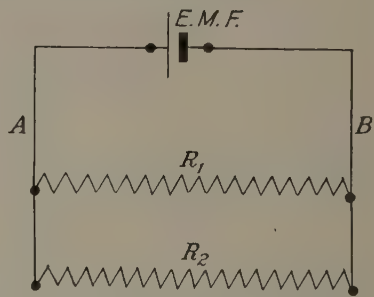


FIG. 12.—A simple parallel circuit (two resistances in parallel).

Referring to Fig. 11, assume each resistance to have 5 ohms resistance, then what would be the effective circuit resistance?

$$R_1(5) + R_2(5) + R_3(5) = 15 \text{ ohms.}$$

The total resistance in the circuit, therefore, would be equivalent to a circuit containing one resistance of 15 ohms, and so on. Thus, the current would be equal to the total e.m.f. divided by the total resistance, or

$$I = \frac{E}{R}.$$

An important point to remember in series circuits is that, for a given voltage, the current at every point in the circuit is inversely proportional to the total resistance of the circuit.

Parallel Circuits.—A parallel circuit is one in which there are two or more parts connected between two points in a circuit. Figure 12 shows a simple parallel circuit consisting of two resist-

ances R_1 and R_2 connected between two points a and b of any circuit. These resistances are assumed to have a value of 10 and 20 ohms, respectively, and to be connected across a potential of 100 volts.

How many amperes are flowing through each resistance and what is the total amperage being drawn from the supply line?

$$R_1 = 10 \text{ ohms.}$$
$$R_2 = 20 \text{ ohms.}$$

Then by Ohm's law as applied to a series circuit, the current flowing through R_1 is found by dividing 10 into 100 or $I = \frac{E}{R}$.

Thus
$$I = \frac{E}{R_1}.$$
$$I = 10 \text{ amp.}$$

Then, the current flowing through R_2 will be found in a like manner to be

$$I = \frac{E}{R_2}$$
$$I = 5 \text{ amp.,}$$

and so on, regardless of the number connected in parallel. The total current flowing in the exterior circuit, or in other words the combined current, is then found by adding the current flow of each part, thus

$$I = I_1 + I_2,$$
or
$$I = 10 + 5 \text{ amp.}$$
$$I = 15 \text{ amp.}$$

In parallel circuits, therefore, the total current flowing through any parallel combination can always be found by applying Ohm's law to each branch and then adding the current value of each branch, as in the last example.

It can be seen, from the above statement, that the total current I is greater than can possibly be obtained through any one branch providing the impressed e.m.f. is kept constant.

From this, it is quite obvious that the joint resistance of any parallel combination is less than the resistance of any one of the branches.

For example, if three resistances of 10, 20, and 30 ohms are connected in parallel, the total effective resistance will be less than the smallest resistance (10). The effective resistance, therefore, can be accurately found by the following formula:

$$R = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}},$$

where
$$R_1 = 10 \text{ ohms.}$$
$$R_2 = 20 \text{ ohms.}$$
$$R_3 = 30 \text{ ohms.}$$

Hence

$$\frac{1}{\frac{6}{60}+\frac{3}{60}+\frac{2}{60}}=\frac{1}{\frac{11}{60}}=\frac{60}{11}.$$

$$R = 5 + \text{ohms}.$$

Series-parallel Circuits.—A series-parallel or parallel-series circuit comprises a combination of series and parallel parts. Figure 13 illustrates three types of series-parallel and parallel-series circuits. Once again Ohm's law must be applied to every part of the circuit. In analyzing more complicated circuits of this type, however, it will be necessary first to reduce each parallel combination to its equivalent series resistance before combining it with the remainder of the circuit. Then, the circuit resistance-voltage drop and current flow can be determined by Ohm's law.

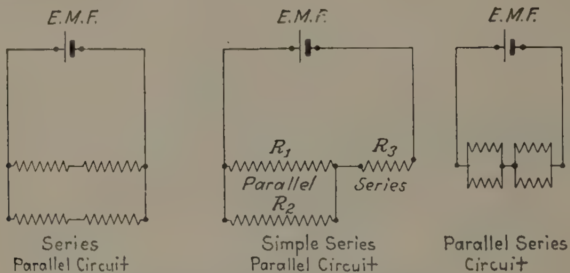


FIG. 13.—A series-parallel circuit.

For example, if R_1 and R_2 is 10 ohms and R_3 is 5 ohms, then by reducing the parallel combination R_1 and R_2 by the parallel formula we find the resistance to be 5 ohms. Then by adding R_3 to the results of R_1 and R_2 we find the total effective resistance to be 10 ohms. The same application can be made to the other two forms of series-parallel, parallel-series, circuits.

Electrical Work.—Work is the overcoming of opposition through a certain distance. Resistance can be overcome, when work is performed. Force may exist without work being performed, as when you push against a wall and do not move it, no work is done, yet the force exists. In an electrical circuit there is a force between the two terminals of a generator or battery but no current can flow through the air between the terminals because the force is not sufficient to overcome the resistance of the air: the same would be true of a generator when running on an

open circuit. When a wire is connected across the terminals, however, then the force overcomes the resistance of the wire and electrons are set into motion around or through the wire, which becomes heated. For example, when a lamp is connected across a generator, the work is represented by the heat and light given by the lamp as well as by the heat given by the remainder of the circuit. Thus, the total work performed is the product of the force, the current, and the time that the current is maintained and is expressed as follows:

$$\text{Electrical work} = E \times I \times T \text{ (time).}$$

Electrically we will call the unit of work the "joule" or the amount of electrical work performed by a current of 1 amp. flowing for 1 sec. under a pressure of 1 volt. This would be analogous to the mechanical unit of work, the foot-pound.

$$1 \text{ joule} = 0.7375 \text{ ft.-lb.}$$
$$1 \text{ ft.-lb.} = 1.356 \text{ joules.}$$

If it is desired to find the amount of "joules" in any electrical circuit

$$J = E \times I \times T.$$

Electrical Power.—Power is the rate at which energy is expended, and is independent of the total work to be accomplished. This unit electrically is called the "watt." To find the rate in *watts* at which energy is expended in a circuit multiply the volts by the amperes thus:

$$W = E \times I.$$

A formula may also be applied to circuits where the wattage is known but in which the current or the voltage are unknown.

$$I = \frac{W}{E}; \quad E = \frac{W}{I}.$$

One watt = 0.7375 ft.-lb. per second or 1 ft.-lb. = 1.356 watt-sec.

One mechanical horsepower = 33,000 ft.-lb. per minute, or

$$\frac{33{,}000}{60} = 550 \text{ ft.-lb. per second.}$$

Hence, to find the number of watts in an electrical horsepower

$$\frac{550}{0.7375} = 746 \text{ watts} = 1 \text{ electrical horsepower}$$

To find the electrical horsepower in any circuit, or part of a circuit,

$$\text{hp.} = \frac{E \times I}{746}.$$

When higher powers are used, watts are usually referred to in "kilowatts," abbreviated kw. One kilowatt equals 1,000 watts, and is about one and one-third times as large as the horsepower unit.

$$\text{Kilowatts} = \frac{E \times I}{1{,}000}.$$

For example, a circuit in which the voltage reading is 250 volts and the current reading is 20 amp., the amount of kilowatts consumed in the circuit would be

$$\text{kw.} = \frac{250 \times 20}{1{,}000} = 5 \text{ kw.}$$

Questions

1. Define an electron.
2. What is meant by the term neutral atom?
3. What is meant by the term electrification?
4. Define electromotive force, current, resistance.
5. What is the difference between the ampere and the coulomb?
6. Give the formula for finding coulombs.
7. What alloy has the lowest electrical resistance?
8. Define Ohm's law.
9. What is the electrical unit for power?
10. What is the difference between power and work?

CHAPTER III

ELECTROMAGNETIC INDUCTION

Electromagnetism.—If a wire carrying a current of electricity is held over a compass needle, the needle will tend to turn at right angles to the conductor, but if the current is turned off, the needle will again resume its original position. The force which made this needle turn at right angles to the conductor was the lines of force, or magnetic field, which surrounded the conductor when the current flowed through it. This field must have been at right angles to the conductor, for it was in this direction that

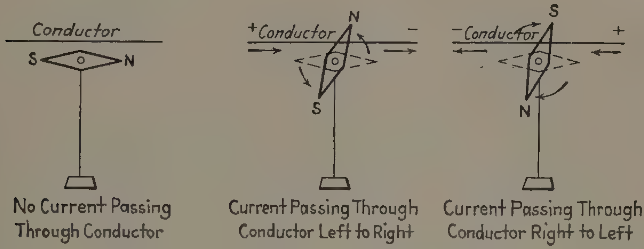


FIG. 14.—Magnetic field about a wire carrying current.

the needle turned when placed in the vicinity of this field (Fig. 14).

If a current in a conductor flows away from the observer, the direction of the lines of force would be around the conductor in the direction followed by the hands of the clock, clockwise. Conversely, if the current flows towards the observer, the lines of force will be in the direction opposite to the movement of the hands of a clock, or counter-clockwise. If two conductors placed side by side carry the current in opposite directions the resultant fields are in opposition (Fig. 15*a*). If the current in two conductors flows in the same direction and they are placed side by side, the fields combine and add to one another's strength

(Fig. 15*b*). If a wire is wound in a coil, therefore, the lines of force in each turn will have the same general direction and will unite with one another, setting up a strong field about the entire coil. The magnetic field through a coil of this kind is similar to that through a bar magnet. If the general direction of the lines of force is from right to left, the left-hand end will become the north pole and the opposite end the south pole. If the current flow through the coil is reversed, the polarity of the ends of the coil will reverse.

A coil consisting of a number of turns of wire with a current flowing through it, when the object is to produce a magnetic

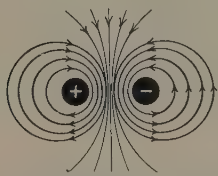


FIG. 15*a*.—Magnetic repulsion (fields repel).

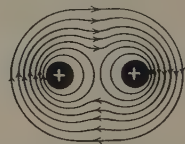


FIG. 15*b*.—Magnetic attraction (fields interlink).

field, is called a "solenoid." The magnetizing power of a solenoid may be greatly increased, several hundred times at least, by merely inserting an iron core or bar of soft iron therein.

Induction.—When a current is first sent through a conductor, the lines of force around the conductor gradually build up from a zero to maximum field. This all happens in a fraction of a second. If the current is suddenly turned off, it is readily seen that the lines of force around the conductor will gradually contract and disappear. This phenomenon must be clearly borne in mind in order that electromagnetic induction may be understood. If a current flowing through a conductor is increased or decreased, the lines of force increase or decrease accordingly. It is, therefore, easily seen that a magnetic field around an electromagnet may be increased or decreased by varying the current flowing through the solenoid.

If a conductor forming a complete electrical circuit is passed through the cross-section of a magnetic field, a current will flow in the conductor as a result of an induced e.m.f., the direction depending upon which way the lines of force are cut by the con-

ductor. This is the most important phenomenon in connection with generation of electricity by mechanical means. It is very important that this be clearly understood. Remember that every time a conductor is cut by lines of force, an e.m.f. is induced in the conductor. If now, a solenoid is taken through which is flowing a varying current, the lines of force about the solenoid will rise and fall as the current varies. As they rise and fall the magnetic field around each turn of the solenoid cuts itself and many adjacent turns and consequently produces a greater e.m.f. than for one turn the amount of which is dependent upon, the number of turns, the amount of current flowing through the turns and the number of lines of force threading the solenoid. This action results in an induced e.m.f. which is in the direction opposite to the impressed e.m.f. of the coil. (The opposing effect is only present when the field is expanding.) This tends to retard the flow. This phenomenon is called self-induction because it is an e.m.f. induced in a conductor by its own magnetic field.

If a conductor is placed in the vicinity of another conductor carrying an e.m.f. of varying intensity, and consequently having a varying field, an e.m.f. will be induced in it because of its being cut by this varying magnetic field. The current in this conductor is called an induced current and is due to the phenomenon called electromagnetic induction.

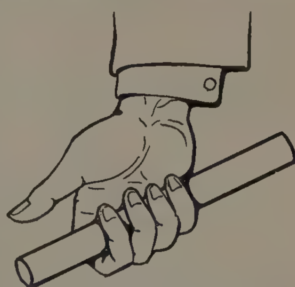


Fig. 16.—Right-hand rule for field direction.

Let us imagine two coils *A* and *B*. A current of varying intensity is flowing through coil *A*. Coil *B* being near coil *A* has a current induced in it by induction. As the field in coil *A* dies down, the lines of force around coil *B* also die down.

In so doing, they induce an e.m.f. in coil *A*, so that a third e.m.f. is produced by induction. First, is the original in coil *A*, second, the induced e.m.f. in coil *B*, and, third, a reinduced e.m.f. in *A* due to *B*. This phenomenon is called mutual induction.

Right-hand Rules.—Several simple rules have been devised to aid in remembering the relationship between the direction of the magnetic lines of force and the current flow. Figure 16 shows an easy way to remember and determine the direction of a magnetic field around a conductor if the direction of the current flow is

known. Grasp the conductor as shown, the thumb pointing in the direction of the flow of current. The finger tips then point in the direction taken by the lines of force as they build up and surround the conductor.

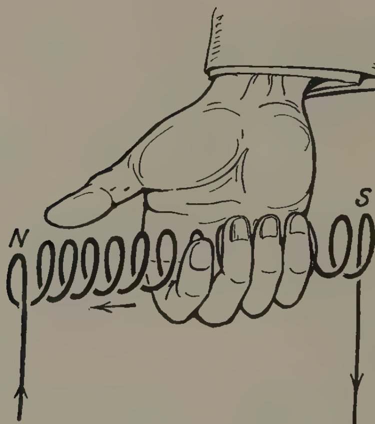


FIG. 17*a*.—Right-hand rule for polarity of solenoid.

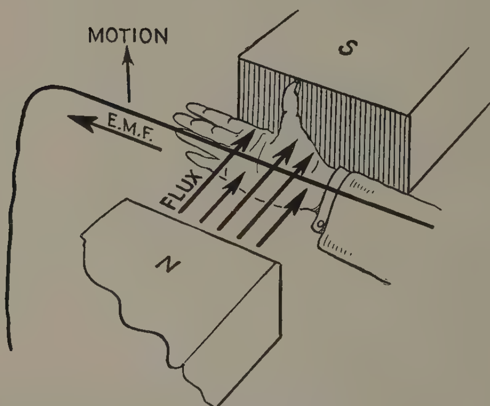


FIG. 17*b*.—Right-hand rule for direction of e.m.f.

The polarity of a solenoid may be determined by grasping the coil as shown in Fig. 17*a*. With the right hand grasp the solenoid so that the fingers point in the direction of the current flow. The

thumb will then point in the direction of the north pole of the magnetic field. Figure 17*b* shows how to determine the direction of current flow in a conductor passing through a magnetic field.

Inductance is spoken of in the abstract as well as in the physical form. Induction is the phenomenon produced when electromagnetic lines of force build up and recede about a conductor. This procedure and its effect are analyzed here. Every conductor carrying a current is surrounded by lines of force. The number of lines depends upon the current. When the current is increased, the number of lines increases and when the current is decreased the flux, as these lines of force are called, also decreases. If the conductor is coiled so that it has one turn, the same line of force will be cut twice. If it has three turns, it is cut three times, and so on, the number of times a line of force is cut depending upon the number of turns in the coil.

Now, as was explained before, the cutting of a conductor by lines of force produces a current therein. It can be understood that, if the magnetic field about a solenoid or helix suddenly collapses, the lines of force will cut the turns of wire and cause an amount of energy to flow through the coil. If this coil is large, much energy is induced and the inductance is said to be large. If, on the other hand, the coil consists of only a few turns, the inductive effect is relatively small and it is called a small inductance. Inductance is, then, that property of a circuit by virtue of which energy may be stored up in electromagnetic form and has the effect of opposing any change of current flow in the circuit.

From the above explanation, it may be seen that induction is not a concrete thing but rather a phenomenon. Technically, this is so, but the electrical radio man has come to call any coil of wire whose chief function depends upon its inductive effect, an inductance.

Self-inductance.—When the "self-inductance" of an electrical circuit is mentioned it is referred to as "that phenomenon whereby an e.m.f. is induced in the circuit itself when the current in the circuit changes, or varies." This important factor the beginner should understand thoroughly in order to comprehend clearly the function of inductances when they are connected in alternating current circuits.

Referring again to the previous paragraph on induction, in which it was explained how a current passing through a wire creates a magnetic field about it, and how this field can be increased by coiling the wire into helical form and inserting into it an iron core, let us consider what happens in the circuit itself when the magnetic field is either expanding or contracting through a variation of the current flow: remembering that whenever a current varies, the magnetic field around the wire correspondingly varies (moves). It is extremely important to grasp the following fact: When a magnetic field appears and disappears, it produces an e.m.f. in all conductors cut by it. It is immaterial whether these conductors belong to a separate circuit, or whether they constitute the circuit (the helical coil referred to above) in which the magnetizing current is flowing.

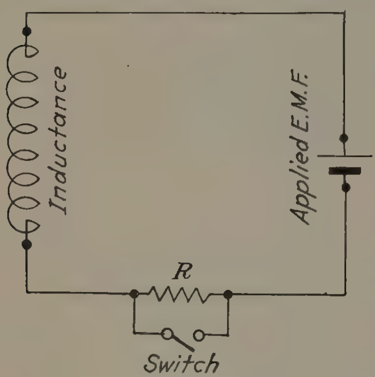


Fig. 18.

The e.m.f. which causes the current to flow through the coil is called the "applied" e.m.f. There is an e.m.f. which is produced by the circuit itself independent of the applied e.m.f., it is a counter e.m.f., due to self-induction. For example, examine Fig. 18. Here is a simple electrical circuit, consisting of a battery, a switch, a resistance, and a coil. In this circuit, a current is flowing continuously, whether the switch is open or closed; the difference being only in the strength of current *i.e.*, when the switch is *open* a minimum of current flows, due to the resistance, and when the switch is *closed* a maximum of current flows because the resistance is then short-circuited.

The student will readily see that in each of these situations there will be a magnetic field present about the coil. Hence, when the switch is open the magnetic field of a certain density extends out from the coil. When the switch is closed, therefore, the field about the coil will increase in density. In other words, the field has actually expanded from a minimum to a maximum density when the switch is closed and from a maximum back

again to a minimum when the switch is opened. Now, it is quite apparent that if the switch should constantly be opened and closed, there would be in evidence a moving magnetic field, expanding and contracting at a definite rate, depending upon the speed with which the circuit is opened and closed. What effect would this action have on the circuit itself? This is one of the most important principles associated with all forms of electrical circuits in which the current is changing or varying. When a current is starting to flow in a conductor, due to an *applied* or *impressed* e.m.f., the magnetic field about the conductor is expanding and becoming denser. During this period of expansion, the field, consisting of magnetic lines of force, is cut through by the wire or coil by which it is produced. This causes a second current to be set up in this conductor, but in an opposite direction, however, to that of the applied or impressed e.m.f. Therefore, during the period of field expansion, the coil or wire acts as an opposition to the applied e.m.f. and thus prevents the current in the circuit from reaching its maximum until the cutting of the field by the conductor has been completed. This continues usually for a fraction of a second only but the significance of this result is readily seen when the circuit is made and broken at a great rate of speed. Thus far, only the results of a starting or expanding field have been noted. When the circuit is broken and the current is decreasing, the process is reversed; the field as it contracts is again cut by the coil, but as this cutting is now in the opposite direction another self-induced e.m.f. is produced, which is now in the same direction as the impressed e.m.f. and which tends, therefore, to prolong the duration of current. The value of the back pressure at *make* is never greater than the impressed e.m.f., otherwise the current could not rise in value. Its value at *break* however, is not limited by any such condition and, therefore, when the break is very sudden, its value at that instant may be very great.

Again, the magnetic field around a steady current represents a certain amount of energy stored up in the surrounding space. For example, it may be said that the energy was supplied at the expense of the current in the circuit when the e.m.f. was started, and that this same energy was returned to the circuit when the current was stopped. The starting of a current in a circuit,

therefore, resembles in a logical manner, the starting of some heavy mass, a grinding wheel, for example. It cannot be started suddenly, nor does it naturally stop suddenly. Here the starting of the wheel would be analogous to a force overcoming the inertia of the mass or in electrical terms the inductive circuit is analogous to a body of great mass. Referring again to the wheel, the amount of energy associated with it when in steady motion, and the magnitude of all the effects depending on that energy, will vary with its mass. This example may be referred to whenever doubt exists as to the function of an inductance connected to a circuit in which the current is changing or varying. "Self-induction" in a circuit, therefore, tends to prevent a change in the strength of the current flowing through it.

Hence it can readily be seen that the greater the number of turns in a coil, or, even more so, the greater the amount of iron in a coil, the greater will be its self-inductance, and therefore, the greater the self-inductance of any circuit the greater will be its property to oppose the e.m.f. impressed upon it. From this it can clearly be understood that there might be a possibility of a circuit having a self-inductance so large that no current of a varying character could pass through it. A coil possessing these properties is called a "choke" coil.

The unit of inductance is the *henry* (h), the value of which depends upon the rate of current variation through a coil, the number of turns of wire in the coil and the amount of iron in the core, if an iron core is used. A coil is said to have an inductance value of one henry if a varying current of one ampere per second produces in it an e.m.f. of one volt. But the inductance unit 1 henry is too large for practical purposes and instead the units *millihenry* and *microhenry* are used which are respectively, one thousandth and one millionth of a henry.

Summary.—Two important rules that the student must remember before proceeding with the next chapter are the classification of the two terms, "self-induction," and "mutual induction."

Self-induction is that phenomenon whereby an e.m.f. is induced in the circuit itself when the current in the circuit changes or varies, and is always in the direction opposite to the impressed e.m.f. during the period that the field rises.

Mutual induction may be defined as that phenomenon between two circuits A and B whereby an e.m.f is induced from circuit A into circuit B when the field in the circuit A expands and contracts due to a varying current flowing in it.

To explain further: look at the Fig. 18*a* in which there are two coils A and B. If a current is caused to flow through coil A there will be immediately induced into coil B an e.m.f. which will in turn induce a tertiary current in coil A. This reaction of induction between two current carrying conductors placed near together (in inductive relation) is termed *mutual induction* because the effects are mutual, from A to B and from B to A.

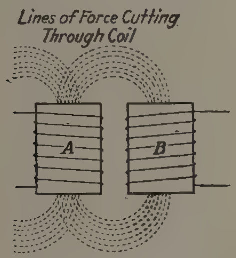


FIG. 18*a*.—Maximum e.m.f. induced in B.

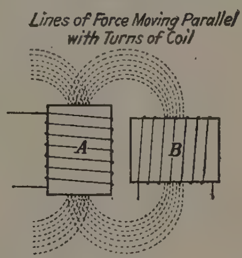


FIG. 18*b*.—Minimum e.m.f. induced in B.

However, if the coils A and B are placed at right angles to one another as in Fig. 18*b* practically no e.m.f. will be induced because the moving magnetic field of coil A will not cut the conductor B. This is due to the magnetic lines of force from coil A moving parallel to the direction of the turn windings in coil B.

It can thus be readily seen that a change in the angular position of coil B in a moving magnetic field would result in a minimum or maximum induction between the coils depending entirely upon their angular relation.

Questions

1. Define electromagnetic induction.
2. What is meant by the term self-induction?
3. When is the greatest opposition offered to an impressed e.m.f.?
4. What are several means with which the self-inductance of a circuit may be increased?
5. What is meant by the term mutual induction?
6. Give a simple illustration of a circuit having high self-inductance.
7. Draw a simple diagram illustrating mutual induction.
8. What is a solenoid?
9. How can the polarity of a solenoid be determined?
10. How can the direction of the magnetic field about a conductor be determined?

CHAPTER IV

ALTERNATING-CURRENT AND DIRECT-CURRENT ALTERNATORS AND GENERATORS

The Simple Alternator.—Figure 19 shows a simple illustration of the alternator principle in which a conducting loop *abcd*, is arranged in a position so that it can be rotated on its horizontal axis in the air space between the two poles of a magnet N and S. The loop has an outlet to two rings and brushes from which the alternating current can be drawn for external use.

It has been shown in the preceding chapter how an e.m.f. may be induced in a conductor by causing it to cut a magnetic field. Bearing this theory in mind, apply it to the elementary alternator and proceed to analyze the induced action in steps.

Position I is the starting point of the loop and, incidentally, represents the neutral position of the loop with respect to the field from N to S. At this instant, the sides of the loop are moving in a direction parallel to the lines of the magnetic field, and the induced e.m.f. at this instant is zero.

If it is assumed the loop is to rotate in a clockwise direction it will be quite evident that the loop upon reaching position II has gone through an angle of 90 deg. and during this time it has cut a certain number of magnetic lines of force. The conductor having moved in the magnetic field, therefore, will have had induced in it an e.m.f., which in turn creates a current flow in the conductor in the direction *ABCD*.

When the loop reaches position III it is again parallel with the magnetic lines of force (flux) and for this instant no e.m.f., is induced; continuing the movement in the clockwise direction up to position IV, the conductor has once more cut a certain number of lines and again an e.m.f., and consequently a current flow is induced. Note carefully, however, that the sides *AB* and *CD* have completely reversed their position, *i.e.* sides *AB* which were at the N pole of the magnet in position II are now at the

S pole of the magnet. Therefore, the e.m.f., which has been generated in the loop during the first half revolution has now

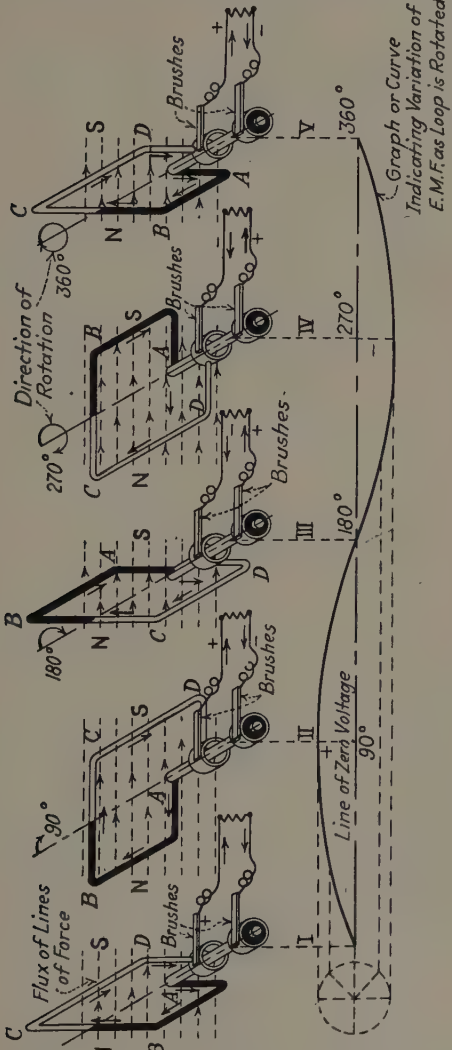


FIG. 19.—Principle of the alternator.

changed its direction. When position V is reached the loop is again parallel with the magnetic flux and no e.m.f., is induced. Sides AB and CD are now again in their starting positions, and

if the loop is again rotated in the same direction another complete cycle of e.m.f. will be generated. It must be clearly understood that the induced e.m.f. at any instant is dependent upon the rate at which the lines of force cut the conductor. For example, if the e.m.f. at the alternator loop terminals measures 100 volts when revolving at a speed of 1,800 r.p.m., then at a speed of 3,000 r.p.m. the e.m.f. would be greater than 100 volts. This can be clearly seen if we consider that the loop cuts more lines of force in the same period of time due to its greater speed. It is now evident that during the 360-deg. movement of the loop two alternations of current have taken place through the external circuit *R*. These two alternations of current constitute one cycle of alternating current and is usually expressed in "cycles

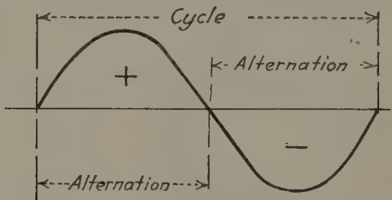


FIG. 20.—One cycle of alternating current.

per second" or "frequency." Thus, an alternator is a device for producing an *alternating current*, or, in other words, a current which reverses its polarity periodically (Fig. 20).

The *frequency* is therefore equal to the number of cycles generated in a second, or is sometimes expressed as the number of alternations per minute. For example, in an alternator having a frequency of 500 cycles per second there are 1,000 alternations a second. It is preferable to specify in cycles per second as this is the more usual practice, for example, a 60-cycle alternator, a 120-cycle alternator, a 500-cycle alternator, and so on.

The following formula shows how the frequency of an alternator may be determined.

$$F = \frac{N}{2} \times \frac{S}{60},$$

where F = frequency in cycle per second.
N = number of field poles.
S = speed of the armature in revolutions per minute.

Example 1.—A certain alternator has 24 field poles and runs at 3,500 r.p.m. What is its frequency?

$$F = \frac{24}{2} \times \frac{3{,}500}{60} = 700 \text{ cycles per second.}$$

Example 2.—An alternator is run at 600 r.p.m. and is to give a frequency of 60 cycles per second. What number of poles is required?

$$N = \frac{2f60}{S},$$

hence

$$N = \frac{2 \times 60 \times 60}{600} = 12 \text{ poles.}$$

Types of Alternators.—The magnets of the alternator are referred to as the "field magnets" or simply the "field." In all alternators, used in radio equipments, the field magnets are electromagnets which are energized by a direct current passing through the winding on the core of each pole in a direction that will keep the poles alternately N and S around the circumference. In Fig. 21, the path of the flux is out from the N pole, across the air gap to the S pole, and so on around the circumference, thus completing the complete field energizing circuit.

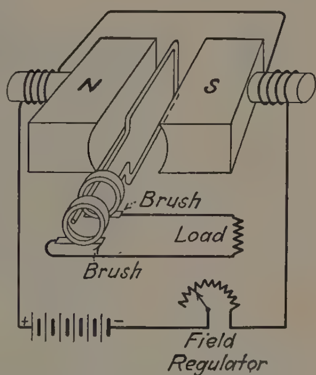


FIG. 21.—The simple alternator.

There are three types of alternators.

1. The revolving armature type.
2. The revolving field type.
3. The inductor revolving type.

The *revolving armature* type has the field poles fastened directly to a frame which, in turn, is bolted to the body casing or bed plate of the generator unit. The armature revolving in this field generates in itself an e.m.f., of alternating characteristic in an identical manner with the simple loop in Fig. 19. This type is shown in Fig. 21 and will be referred to as the "revolving armature" or "stator field" alternator.

The *revolving field* type is generally used in large alternators in which high voltages are to be generated. This is shown in Fig. 22. Here the rotating field coils are excited by a direct-current e.m.f. whereby an alternating e.m.f. is induced in the stationary

poles windings as soon as the field is rotated. Note the difference: in the stationary field-type alternator the alternating e.m.f. is generated in the rotating armature winding and taken out to the external circuit by collector rings, whereas in the revolving field type the alternating e.m.f. is taken out from the stationary pole windings, now the armature, when the rotating field is excited by a direct current through collector rings. The student will note that in either type of alternator the theory of induction holds true, *i.e.*, an e.m.f. may be induced into a conductor if the conductor is moved in a magnetic field or, an e.m.f. may be induced into a conductor if the conductor is placed in a moving magnetic field.

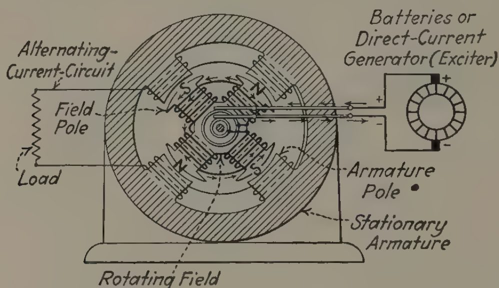


Fig. 22.—Rotating field-type alternator.

In the first type of alternator the alternating e.m.f. is generated in the armature if it is revolving in a properly excited stationary field and the alternating current can then be taken from the armature by collector rings and, similarly, an alternating current can be taken directly from the stationary winding of the second type of alternator when the field is rotating around it, provided the rotating field is properly excited as in Fig. 22. In other words, the stator coils take the place of the rotating armature in type two and might readily be referred to as a "stator armature."

Inductor Alternator.—In the inductor alternator the armature and field windings are fixed, but a revolving rotor of steel with toothed projections rotates in the magnetic path of both windings. This rotor is a solid mass of steel and carries no winding (Fig. 23). The theoretical action can be clearly understood from Fig. 24*a*. The rotor when revolving in the excited magnetic field periodically varies the reluctance. (The reluctance of a magnetic

material may be defined as its opposition to the creating of magnetic lines of force in a material. In other words the reluctance is to a magnetic body as resistance is to an electrical

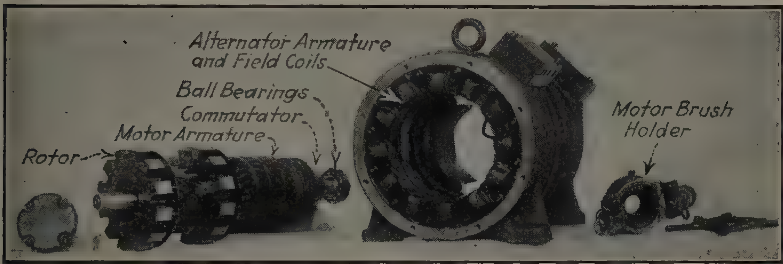


FIG. 23.—Parts of an inductor-type alternator.

body.) And thus this periodical variation produces a constant increasing and decreasing effect upon the magnetic flux. There-

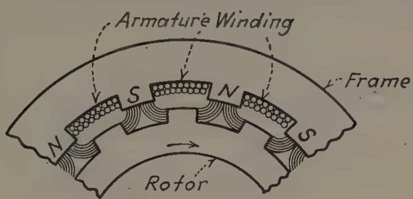


FIG. 24a.—A section of an inductor-type alternator.

fore, when the flux is increasing, the induced e.m.f. will have a certain polarity. Then upon decrease the induced e.m.f. reverses

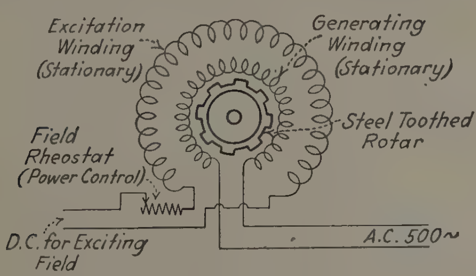


FIG. 24b.—Wiring diagram inductor-type alternator.

and an alternating e.m.f. is generated. This type of alternator is used in practically all of the commercial 500-cycle generators and in the future will be drawn as in Fig. 24b.

The *direct-current generator* may be distinguished by the commutator which takes the place of the slip rings. The function of the commutator is to connect the brushes automatically to a given armature coil when the current in that coil is flowing in a given direction. It will be remembered from the explanation of the alternator that a current will be induced in the armature coil in a certain direction when it is passing through the flux of the field in a certain direction. Now, if this coil can be immediately disconnected as soon as it begins to cut the lines of force in the opposite direction, at which time the induced current reverses itself, and another coil passing the same way but sometwhat later (fraction of a second) is connected to take its place, a series of

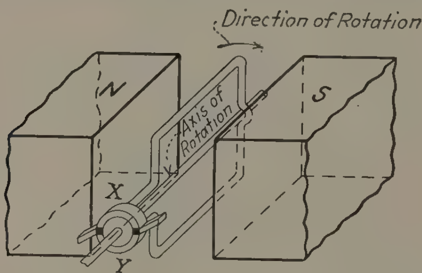


FIG. 25.—A simple direct-current generator.

current pulses all in the one direction will be conducted to the brushes. If, then, these pulses occur in very rapid succession, the effect of a current of constant value will be obtained. This is exactly what happens in the direct current generator. You will note that a direct-current generator is different from an alternator in that it does not produce alternating current but an even varying pulsating current in one direction only.

Figure 25 shows an elementary type of commutator with only two segments, as sections X and Y are called. In the case of commercial-type machines, the commutator may have from 20 to 100 or more segments. The commutator is made of copper, and each segment is insulated from its neighbor, and the commutator as a whole well insulated from the shaft.

Direct-current generators are always made with a stationary field and a rotating armature. There are three methods of connecting the field and the armature, each of which is good for a

particular purpose. These methods of connection are shown in Figs. 26*a*, *b*, and *c*. They are known as shunt, series, and compound connections.

The direct-current generator is usually self-exciting and it is not necessary to excite the field separately as with the alternator. The exciting current for the direct-current generator is obtained from its own armature. By following out the path of the current in a machine of this type it will be noted that any current, or portion of that current, which flows through the armature also flows through the field windings. The fields of the direct-current generator have residual magnetism which is that magnetism which remains in the fields in a small quantity after the machine has come to a standstill. This residual magnetism is enough so that when the armature commences to rotate there are enough lines of force surrounding it to induce a small current in the armature windings. As this current flows through the armature it must also flow through the field. As soon as this happens the field commences to increase, and as the field increases, it increases the current induced in the armature. This continues until the machine has "built up" at which time it is generating its rated voltage at a predetermined rate of speed.

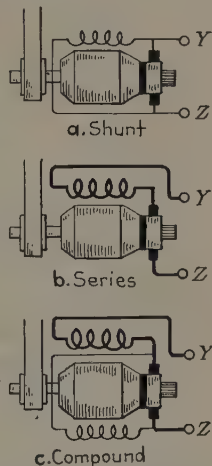


FIG. 26.—Three types of direct-current generator windings.

The various methods of connecting the field and armature of the direct current generator will now be considered. When the field and armature are connected directly in series, it is called a series machine. When the field is connected in shunt or parallel (field across armature) it is called a shunt machine. When a machine has two field windings, one series and one shunt-field, it is called a compound machine. These methods of connection were referred to before and are shown in Fig. 26.

Questions

1. What is a generator?
2. Upon what principle does the alternator function?
3. What are some types of alternators?

4. What is the definition of frequency?
5. Give the formula for finding the frequency of an alternator.
6. Describe the inductor type alternator.
7. Describe the direct-current generator.
8. What is the difference between an alternator and a direct-current generator?
9. Draw a diagram of a shunt-wound generator.
10. If the generator field winding burned out what would be the effect?

CHAPTER V

MOTORS AND ARMATURES

Electric Motors.—An electric motor is a device for converting electrical energy into mechanical energy. The function of a motor is just the opposite from that of a direct-current generator or alternator, as defined in the previous lesson. A motor will produce mechanical energy only when an external source of current is forced through its windings by an impressed voltage.

The *direct-current motor* is the same as the direct-current generator in details of construction and may be used as such. The basic principles under which it operates are explained as follows: When a wire carrying no current lies in a parallel magnetic field, the magnetic lines pass from one pole to the other undisturbed whether the wire be at rest or in motion. When a current flows, however, it sets up a circular magnetic field of its own about the wire or conductor. The direction of travel of the circular lines in relation to the direction of current through the conductor is the same as that of a right-hand screw or bolt; the threads represent the circular lines, and, when the bolt is turned, its forward direction represents the travel of the current. This circular field distorts the parallel magnetic field in which the conductor lies, making the lines denser on one side and less dense on the other side of it. The conductor then tends to move out of the magnetic field at right angles to both the field and the direction of current.

When an external source of electromotive force or e.m.f., is applied to the terminals of a direct-current motor, a current is forced through the armature windings and the field. That portion of the current which passes through the field windings, sets up the magnetic field between the pole faces. The armature conductors lying in this magnetic field and carrying current are repelled out of the magnetic lines and other conductors are carried in between the pole faces. The current flowing in the

conductors just entering the magnetic field is kept in the same direction as that in the conductors leaving the field by means of the commutator, which reverses the current in the armature coils at the instant the coil is at the neutral point between poles. Figure 27 shows the attraction and repulsion between the magnetic fields and the conductors of a motor.

The *commutator* is a device for changing the direction of current flow in the armature coils of a direct-current motor and to change or rectify an alternating current, or e.m.f., in the case of a

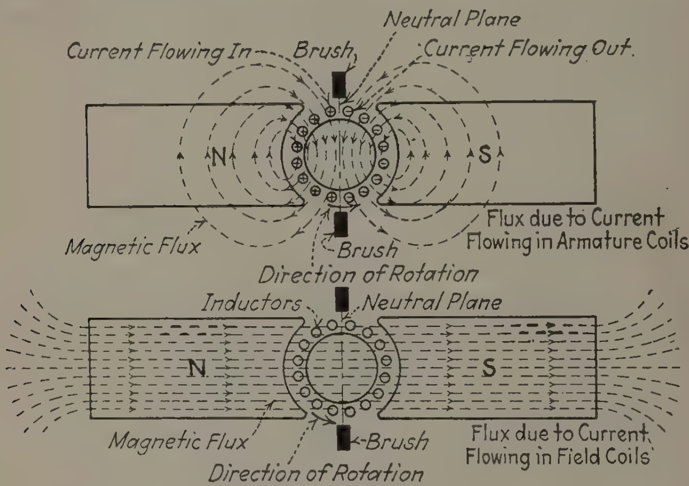


FIG. 27.—Effect of armature and field current.

direct-current generator. The function of the commutator on a direct-current motor is to maintain the proper direction of current flow in the armature coils in relation to the magnetic field, so that the rotative effort of all coils will be in the same direction. All direct-current motors are equipped with commutators, and they are also used on some types of alternating current motors.

Torque is the measure of the tendency in a body to rotate. It may be expressed in foot-pounds, or in pounds of force at a given radius. It is not necessary that there be motion in order that there be torque. As an example, suppose the emergency brake on an automobile is tightly set so that the rear wheels cannot possibly move. If power is now applied, not enough to

cause the brakes to give away, a force is exerted on the wheels although there is no motion. Torque is the twisting power exerted on an object. It is easily seen that an enormous torque may be applied and not a single foot-pound of work done. Torque in an electric motor varies as the product of the field density (flux) times the armature current.

Types of Motors.—Direct-current motors have their fields and armatures connected in various ways. Figure 26 shows the kinds of generator connections used and this figure will also serve to explain the motor connections. It is to be remembered that the only difference between a direct-current motor and a direct-current generator is that one is driven mechanically and sets electricity in motion, while the other is driven electrically and produces mechanical energy.

Shunt Motor.—The shunt motor is used for service in which constant speed is an important factor. This type of motor, once it has reached full speed, will maintain this speed in a very steady way, regardless of variation of the load.

In order to understand why this type of motor behaves in this way, look at Fig. 26*a*. Assume that a current is impressed across *Y* and *Z*. This will excite the field windings. As long as the impressed e.m.f. remains constant, the field strength and excitation current will remain constant. A current which is in unit proportion to this excitation current will be forced through the armature. The motor armature now commences to rotate and attains a certain speed. The armature is now producing a counter e.m.f., due to its conductors cutting the magnetic field, which, when the motor is running at no load, is very nearly equal to the impressed e.m.f.; therefore, at no load practically no current (amperes) is flowing through the motor.

Assume that a load is suddenly thrown on the motor; it slows down slightly, but not very much. As this happens the armature will cut a smaller number of lines of force per second and will produce a smaller counter e.m.f. Because of this the current (amperes) flowing through the armature coming from the source *YX* increases. This increases the torque (turning effort) of the armature and the original speed of the motor is maintained. Now if the load is taken off, the motor speeds up somewhat, the armature cuts more lines of force per second, which in turn

induces in the armature a greater counter e.m.f., preventing the motor from gaining more speed. It is, of course, true that a shunt motor does vary slightly in speed, but for correctly designed machines this variation is so slight that for the purpose of theoretical explanation it may be disregarded.

Series Motor.—This type of motor, shown in Fig. 26*b*, is used on service requiring quick acceleration with a heavy load, such as electric railroad trains, locomotives, street cars, electric hoists, etc. The load must never be taken off a series motor, for if this happens it will race and tear itself to pieces. The torque of the series motor varies almost as the square of the armature current (amperes). It will be noticed that the field and armature windings in this type are connected in series and it is from this that it takes its name. Series motors have a very powerful starting torque. Bear in mind that a rapidly rotating armature sets up a counter e.m.f. which is, in effect, the same as resistance, in that it tends to oppose the flow of current through the armature. When the motor is at a standstill the resistance of the armature is relatively low and the current which can force its way through is relatively large. As the armature current is large, so must the field current be large, and the result is a dense magnetic field produced by the field coils. Furthermore, as the torque varies as the product of the field density times the armature current, the torque in the series motor is very large at the start. As its speed increases, the armature current, due to counter e.m.f., decreases the field current, the field density, and finally the torque. When the torque decreases the speed decreases. From the above explanation it is seen that the speed of the series motor would vary directly with the load.

Compound Motor.—This type of motor has the characteristics of both the series and the shunt machine. It is employed in such services as require a large starting torque and a constant speed under load. Because of its series field, it is able to gain speed quickly under a load; and because of its shunt field it maintains an even speed when the load is suddenly taken away or varied. These are designed especially for constant speed under quick changes from no load to full load. In a radio transmitter the motor is practically running light until the key is depressed when full load is thrown upon it immediately.

Armatures and Armature Windings.—Since the time of the development of the electric dynamo, two forms of armature windings have been used, *i.e.*, ring windings and drum windings.

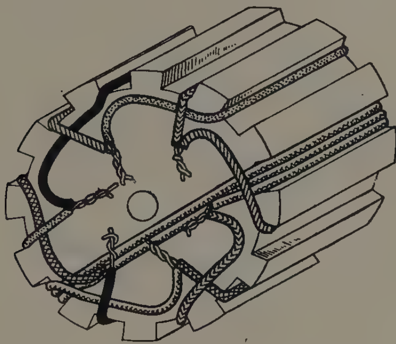


FIG. 28.—A drum-wound armature.

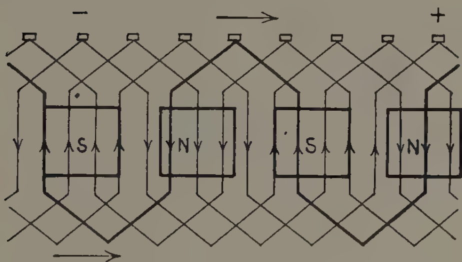


FIG. 29.—Wave-wound armature winding.

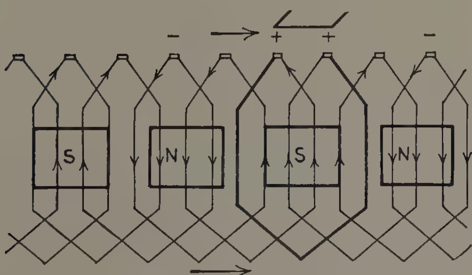


FIG. 30.—Lap-wound armature winding.

The latter is the only type used at the present time. Figure 28 shows the general form of the drum-wound armature. The core

is made up of a number of thin sheets or laminations of soft iron which are mounted on the armature shaft. The laminations are so cut that when they are put together they form grooves into which the armature coils fit snugly. The coils are placed lengthwise in the slots and the two terminals of each coil are connected to two segments of the commutator.

There are two general forms used in winding drum armatures—the lap winding and the wave winding. In order that the student may understand how these terminals are connected to the commutator segments, an illustration of both windings is given in Figs. 29 and 30.

Differentially Wound Motor.—The differentially wound motor is a compound machine on which the series field is connected so

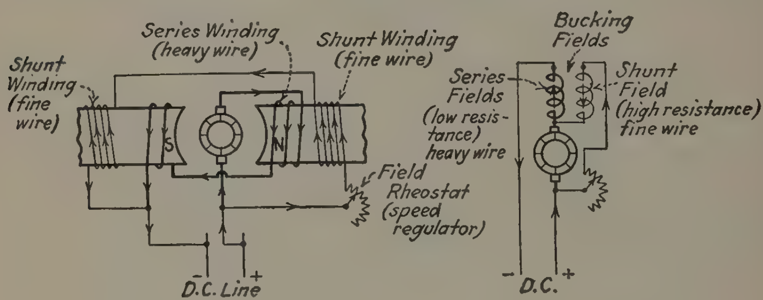


FIG. 31.—A differentially wound compound motor.

that it is in opposition to the shunt field. This results in an automatic regulation of speed under varying loads. Remember that a weak field permits the motor to speed up. Now then look at the diagram (Fig. 31) which shows the fields as being opposed one to the other. Imagine the motor running at normal speed. If a sudden load is thrown on the machine it will slow down just slightly. As this happens the counter e.m.f., produced by the motor armature decreases, allowing more current to flow through the armature circuit. The series field of the differentially compounded motor is, as in all other compound machines, in series with the armature and, therefore, if the armature current is increased, the series-field current increases, which in turn increases the field of force produced by this field. But this increase in field density instead of augmenting the field of the

whole machine, bucks the shunt field (it is connected in opposition), and the resultant is a weaker field, which allows the machine to increase its speed.

When the load is decreased, the current in the armature is decreased, and the series or opposition field, as it might be called, is also decreased, which allows the shunt field to exert its full influence to produce a strong field and thereby prevents the armature from turning too rapidly.

It is seen, therefore, that the series field of a differentially compounded motor serves as a very good speed regulator. This type of motor is used to a considerable extent with radio equipments.

Dynamotor and Rotary Converter.—These machines use the same armature both for the purpose of a motor and a generator. The principal advantage of this construction is that the armature is much shorter than the ordinary motor generator armature and, therefore, only two bearings are required, and the machine as a whole takes up much less space. They are employed to generate an alternating current from a direct-current source of supply, and vice versa.

The rotary converter has a single winding for both alternating and direct current, but the dynamotor has two distinct windings, one for the motor and the other for the generating functions of the machine.

Questions

1. What is an electric motor?
2. Upon what principle does it operate?
3. What is the function of the commutator?
4. What are three types of motors?
5. What is meant by the term counter e.m.f.?
6. How can the speed of a motor be increased?
7. Draw a diagram of a simple shunt-wound motor.
8. What are two types of armature windings?
9. Describe a differential compound motor.
10. What is a rotary converter?

CHAPTER VI

STARTING DEVICES

Hand Starters.—Figure 32 shows one of the most common types of hand starters. It is here shown connected to a shunt-wound motor. The function of the starting box is to prevent the armature of the motor from being burned out, which would surely happen if the current was applied instantaneously by merely closing a switch. A study of the diagram will show that the starting box consists of a number of resistance coils which are gradually cut out of the circuit as the handle is pulled over towards the right. The starting box resistance compensates

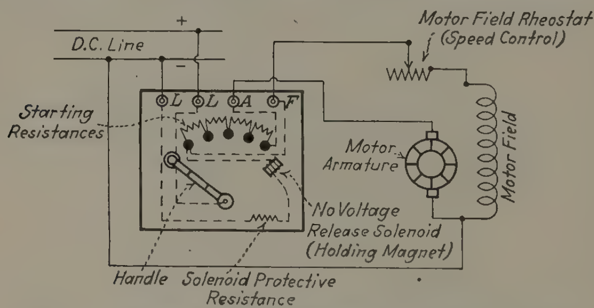


FIG. 32.—General Electric starting box and shunt motor.

for the low counter e.m.f. of the motor armature, which is very low until it has attained full speed.

The counter e.m.f. builds up, as the speed of the machine increases and the resistance of the hand starter may, therefore, be gradually decreased.

Every hand starter has a no-voltage release magnet or a no-field release magnet. This magnet if in the field circuit, and should the current in the field circuit be interrupted for any reason, will lose its magnetism and the handle will fly back to the *off* position. The handle is fitted with a spring which tends to

keep it on the *off* position and it will not stay over to the full speed point unless the attraction of the release magnet is strong enough to hold it there. The starting box shown in Fig. 32 is the type made by the General Electric Company, and has four connecting posts, indicated in the diagram by the letters *L*, *L*, *A*, *F*, which mean lines, armature, and field.

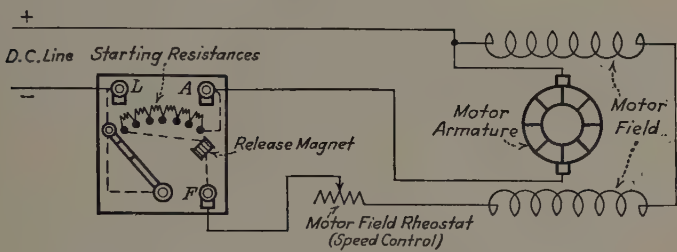


FIG. 33.—Cutler-Hammer starting box and shunt-wound motor.

Another type of starter commonly used is made by the Cutler-Hammer Electric Manufacturing Company, and is fitted with three connecting posts. This starter is connected somewhat different from the four-post type and is shown in Fig. 33.

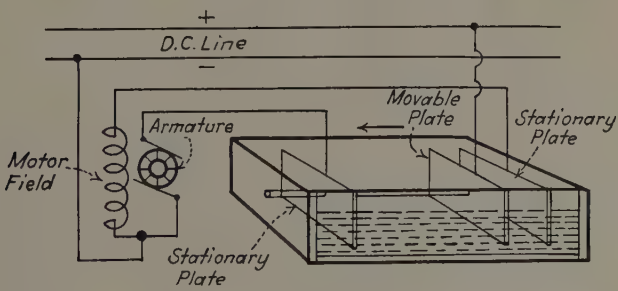


FIG. 34.—Salt-water rheostat.

The handle of the starter must be pulled over very slowly, as the motor must be started neither too rapidly nor too slowly. If the motor is started too quickly, the fuses in the line will blow, or if the circuit is provided with circuit breakers, they will immediately open (see page 87). The reason for this is that the motor armature, as was explained before, has a very low resistance and, therefore, draws a very heavy current until it attains

its regular speed. There is no special rule to follow in starting the motor with a hand starter, but the speed at which the handle should be moved over can soon be determined by gaging the acceleration of the motor. Radio transmitting set motors are relatively small and are usually started in from 15 to 20 sec.

The resistance coils of the hand starter are meant for temporary starting duty only, and if the current is allowed to flow through them for too long a time, it might result in one of them burning out. Pulling the handle over too slowly would cause this, and would have the above result. The remedy for a burnt-out resistance coil is to short-circuit it until it can be repaired. If more than one resistance unit is burnt out, however, it would very likely be dangerous to use the box at all. It would be better if some emergency device, such as the water rheostat shown in Fig. 34 were used.

Automatic Motor Starters.—Figure 35 shows a complete circuit diagram of the automatic starter used on the Radio Corporation P-8 2-kw. 500-cycle set. The advantage of the automatic starter over the hand starter is that the former possesses the advantage of uniform acceleration of the motor when starting. There is less danger, therefore, of injuring the motor or the fuses in the line. There are numerous types of automatic starters on the market, but as the principle under which they operate is the same, only the type shown in Fig. 35 will be discussed. This automatic starter is equipped with an overload relay switch which acts as a main-line circuit breaker. It will be observed that there are three resistance units connected in series with the motor armature. The field winding of the motor is connected in shunt with the direct-current line through a field rheostat. This rheostat regulates the speed of the motor generator set as a whole and, consequently, the frequency of the alternator. The alternator voltage is controlled by a field rheostat as shown. The antenna switch controls the starting and stopping of the motor generator set. It will be noticed that the generator field windings remain open until the last contact to the right, on the automatic starter, is closed. As soon as the starting circuit is closed, the plunger of the automatic starter moves upward in the direction of the arrow. As this movement continues, the resistance is cut out gradually in three steps.

The overload relay has a tripping magnet and a holding magnet. If, in any way, more than a predetermined number of amperes flows through the tripping magnet, the lever of the overload relay is drawn up, breaking the circuit to the automatic starter. It will stay in this position until the trouble, or the cause of the excessive current through the armature, is remedied.

Electric Controller & Manufacturing Co. Automatic Starter.—When the line switch, *LS*, is closed, (Fig. 35*a*) it connects two circuits; one through the main contact, *MC*, to the motor and the other through the auxiliary contact, *AC*, to the shunt holding

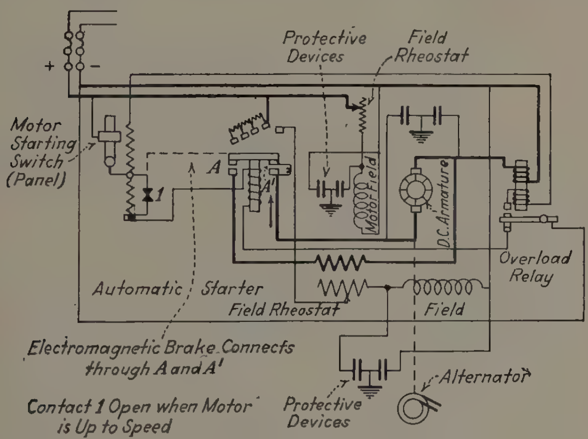


FIG. 35.—Automatic motor starter.

coil *SHC*. With the line switch closed, current will flow from the positive side of the line (+) through the armature, all of the starting resistances, R_3, R_2 and R_1, through the coil C_1 and to the negative side (−) of the d.c. line. Current will also flow through the shunt field. The motor starts and as it gains speed the current flowing through the armature becomes smaller. When the motor current is reduced to a certain amount, C_1 operates, and its contact plate, CP_1, makes contact with the laminated brushes, B_1. Current now flows from positive through the line switch, armature, R_3, R_2, Coil C_2, the brushes and contact plate B_1 and CP_1, operating Coil C_1 and then to the negative side of the line. *The resistor, R_1, has been short circuited and the operating coil of contactor 2 has been inserted in the motor circuit.*

The short circuiting of R_1 increases the armature current, but as the motor continues to gain speed the current is reduced to the same amount as before; Contactor 2 operates, and CP_2 makes contact with B_2. This operation now short circuits R_1 and R_2 and inserts the operating coil of contactor 3 into the armature circuit.

As before, the motor current is increased, but as the motor gains speed the current is again reduced; C_3 operates causing CP_3 to make contact with B_3. All of the operating coils and all of the starting resistances are now short circuited and the armature is getting full line voltage and is revolving at full speed.

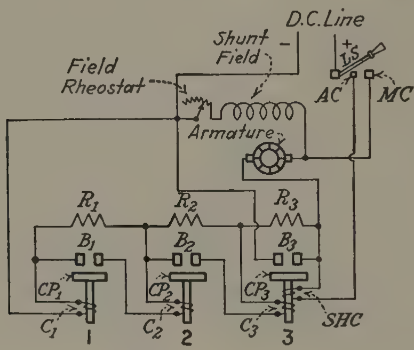


FIG. 35a.—The Electric Controller and Mfg. Co.'s automatic starter (Type A series contactor).

Since the operating coils are short circuited, practically no current passes through them, and C_1 and C_2 drop open, but C_3 is held closed by its shunt holding coil *SHC*. This is a small shunt coil, in the top of the contactor, which is not strong enough to operate the contactor, but is strong enough to hold it closed after the series operating coil has closed the contactor. If the motor is running upon a light load, the motor current may become so small that the series coil would not hold the contactor closed, and hence the shunt holding coil is used.

Questions

1. What is the function of the starting box?
2. Draw a diagram of a shunt motor connected to a starting box.
3. Do the starting resistances function permanently or temporarily?
4. Draw a diagram of an automatic starter.
5. Explain fully its operation.

CHAPTER VII

PRIMARY AND SECONDARY CELLS

The Production of Electromotive Forces by Chemical Action.—When two dissimilar substances are placed apart in certain chemical solutions, a difference of potential will be found to exist between them. Of these substances, copper and zinc, or carbon and zinc, immersed in a solution of sulphuric acid and water, are most commonly known.

Figure 36 shows the essential parts of a simple cell in which two dissimilar plates of carbon or zinc, or copper and zinc, are immersed in a dilute solution of sulphuric acid. Here the difference of potential between the plates is generated by an attack by the acid upon one of the plates (zinc). This results in an evolution of hydrogen gas from the zinc plate but none from the copper plate. As soon as the two wires are connected at the terminals of the cell, however, an increased evolution of gas will result which now comes from both plates.

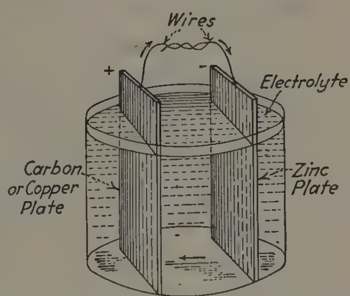


FIG. 36.—The simple primary wet cell.

This action results in the production of an e.m.f. which causes a current to flow through the two connected wires. Cells which are capable of producing this effect are called "primary" or "voltaic" cells.

Theoretical Action of Primary Cells.—When zinc dissolves in sulphuric acid, energy is liberated in heat, which raises the temperature of the solution. It is quite true that this generation of heat may be accepted as a definite amount of energy expended, but when a piece of zinc is placed in a solution of sulphuric acid, or even of common salt in conjunction with a piece of carbon or copper, other possibilities arise. It is this point

that naturally interests the student. What are the other possibilities? The obvious question is: How does the chemical action produce an electromotive force which results in a flow of current through the two wires from the positive (+) to the negative (−) point?

The chemical structure of the sulphuric acid must first be analyzed. All substance is made up of a combination of atoms and when these atoms are of unlike polarity they may tend to combine. If they do, the combined effect is called a molecule.

When sulphuric acid is mentioned, therefore, a certain number of atoms which have combining properties must be conceived. It is for this reason that the formula H_2SO_4 is called a molecule of sulphuric acid.

$$
\begin{aligned}
H_2 &= 2 \text{ hydrogen atoms.}\\
S &= 1 \text{ sulphur atom.}\\
O_4 &= 4 \text{ oxygen atoms.}
\end{aligned}
$$

When the H_2SO_4 molecules are dissolved in water, part of them will become broken up. The extent of the break depends upon the percentage of dilution, which is found to increase with the dilution of the solution. Thus, instead of H_2SO_4, H, H, and SO_4 are obtained. These particles have now been dissociated from their ordinary state H_2SO_4 to H, H, and SO_4, and, therefore, they do not maintain their ordinary chemical properties because each carries an electric charge.

When atoms are in this broken-up state they are called free atoms and, of course, are in a charged condition. Sometimes one kind of an atom carries more charge than another kind, but the greater charge is always some simple multiple of the smaller one. It is quite probable that the electrical forces due to these charges are the cause of chemical relationship.

Thus, when a charged atom, or atoms, is meant they are called "ions." If the charge is removed, the particle is no longer called an ion, and instantaneously resumes its ordinary chemical behavior.

In accordance with the above theory, a dilute solution of sulphuric acid contains a number of free hydrogen ions, each one having a positive charge, and half of that number of the SO_4 combinations will have a double negative charge. Therefore,

as soon as a plate of zinc and a plate of copper are placed in the solution of sulphuric acid there is immediately a tendency for the zinc Zn to combine with the SO_4 to form zinc sulphate ($ZnSO_4$). This combining effect, it will be seen, is due to the breaking up of the zinc atoms at the surface of the zinc into a positive and a negative particle, the positive particle being called a "zinc ion" and the negative particle an "electron." The SO_4 charge of negative polarity, therefore, will tend to combine with the zinc ion of positive polarity and will form the zinc sulphate. This sulphate, which is now a neutral combination of atoms, dissolves in the water and is of no value in the operation of the cell.

The free electrons, or negative charges, are still present, however, having been dissociated from their positive partners when the latter combined with the SO_4. This leaves the free electrons of the zinc and the positive ions H, of the electrolyte in a sort of a strained state which will tend to create a movement of electricity when the two plates of copper and zinc are connected externally by some conducting material. In other words, the zinc now has an accumulation of electrons upon it and as soon as an external wire is connected from the zinc to the copper terminals the electrons will move up through the zinc plate and around the external conductor to the copper plate, which is the other electrode of the cell. This movement of electrons around the external wire from the zinc to the copper is due to the tendency of the electrons on the zinc to repel one another and, therefore, an upward movement through the conductor results. As soon as the electron reaches the copper plate, having passed through the external conductor, the remaining positive ion H, of the electrolyte is attracted to the copper strip. Here each positive ion combines with a negative electron which has just been passed through the conductor from the zinc. The combining of these two particles forms an atom of hydrogen. Hence, these hydrogen atoms form into bubbles of hydrogen, rise to the surface, and evaporate into the atmosphere.

The student will readily see from the above theory, that there is a constant movement of negative ions SO_4 to the zinc plate and a movement of hydrogen positive ions to the copper plate, inside of the cell which in turn generates a movement of electrons through

the external circuit from the zinc to the copper terminals. The electronic flow is, therefore, always in one direction whenever the circuit is closed, even though there are two internal flows in different directions, *i.e.*: the *negative ion* current from the electrolyte to the zinc plate and the *positive ion* current toward the copper plate.

It is quite evident that this complete chemical action which takes place in a cell will create a dissipation of the zinc, during the period that the cell is generating energy, and that the rate of this dissipation depends upon the rate of energy delivered. The lower the resistance of the wire across the two plates the greater the rate of current flow and, obviously, the greater will be the dissipation of the zinc and the solution. Incidentally, the formation of hydrogen bubbles on the positive plates also tends to increase the counter e.m.f. of the cell and, obviously, if the counter e.m.f. is high the effective e.m.f. will be considerably decreased. If the counter e.m.f. is high, therefore the effective e.m.f. will be correspondingly lowered and an obvious decrease in the external current flow will result. Sometimes the effective e.m.f. may be considerably below normal, due to the formation of hydrogen on the copper plate, and not due to the dissipation of the zinc. In this case the hydrogen film could be brushed off and the internal activity could be again increased. The effect of the hydrogen film on the copper plate is known as "polarization" and can be removed either by chemical or mechanical means. Of course, the removal would be of no value if the zinc has become dissipated.

Local Action.—If a strip of zinc containing minute particles of impurities is immersed in a solution of acid, there might arise an internal action extremely detrimental to the life of the cell. For example, when a piece of commercial zinc is immersed in acid it frequently contains small particles of carbon imbedded in the surface. Now, if a primary cell consists of two individual elements of copper, or carbon, and zinc immersed in a solution of acid, it can readily be seen that an impurity in one of the active elements might produce a chemical action in one material itself independent of the other and thus produce a constant chemical action which dissipates the cell and contributes nothing to the external circuit.

Local action might briefly be defined as, that phenomena whereby small internal currents are set up in the cell due to impurities in the active materials of the electrolyte which will seriously impair the life of the cell.

The rate of zinc dissipation and local action may, however, be minimized by coating the zinc with mercury. This is called "amalgamation."

The Dry Cell.—The dry cell in theoretical operation is identical with the wet cell just described, with the exception that the elec-

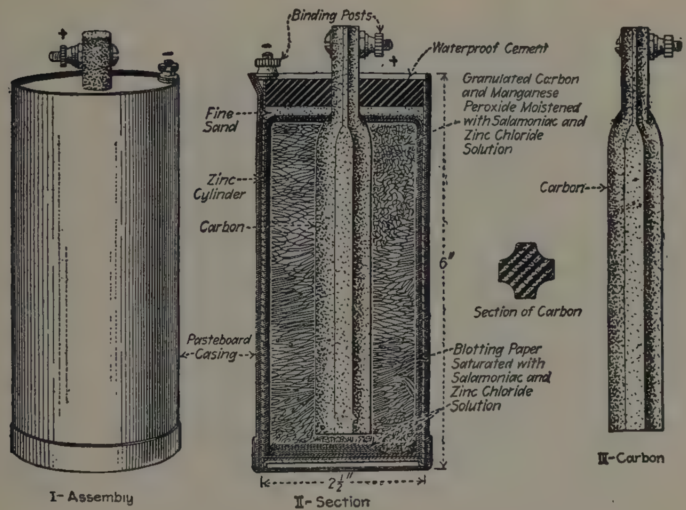


Fig. 37.—The simple primary dry cell.

trolyte is in the form of a paste which will produce the same chemical action as did the sulphuric-acid cell upon the zinc and copper.

Here the two electrodes are still the same, carbon and zinc, and in place of the dilute sulphuric-acid solution, a paste of granulated carbon and manganese peroxide moistened with a salamoniac and a zinc chloride solution (Fig. 37) is used.

The e.m.f. at the terminals of the dry cell is about 1.5 volts and the cell may be used until the e.m.f. has dropped to about 1 volt. The life of the cell is again dependent upon its internal resistance.

The Standard Cell.—The most commonly known standard cell is the Weston cadmium cell which is used in laboratories where a

voltage of known and fixed value is required for comparison and calibration of electrical instruments. These cells are not required to have large current capacities, as they are used only for standard pressure indication and, therefore, in order to maintain a fixed reading must have a high internal resistance. This is in the vicinity of 900 ohms and sometimes an additional resistance is placed in series with it to limit the current flow.

The Weston cell maintains the international volt. It has an e.m.f. of 1.0183 international volts at 17° C. (Fig. 38).

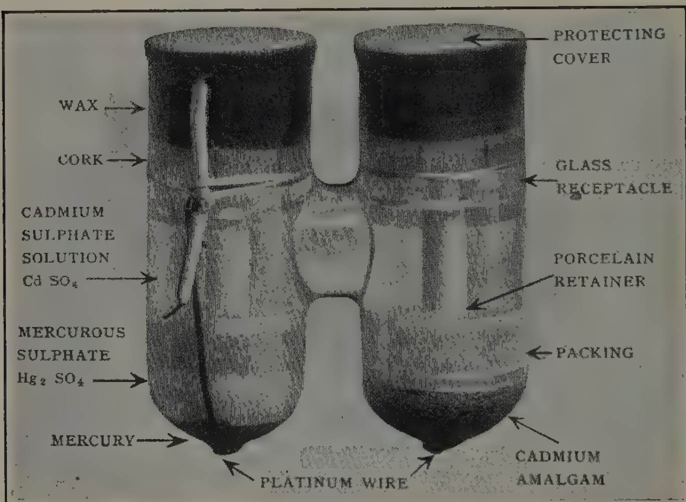


FIG. 38.—The Weston standard cell.

The Voltage of a Cell.—The voltage of a cell is determined solely by the character of the active materials and the electrolyte density. It is evident, therefore, that in order to obtain high voltages a number of cells must be connected in series, that is, the carbon of one cell is connected with the zinc of the next, and so on as in Fig. 39.

There is a certain difference of potential between the zinc and the carbon of cell A, and an equal difference between the zinc and the carbon of cell B, but when the zinc of A and the carbon of B are joined, their potentials are equalized, therefore, the difference

of potential between two cells arranged in series is twice that of one.

The resistance, however, of two cells in series is twice that of one, since the length of the electrolyte traversed is twice that of

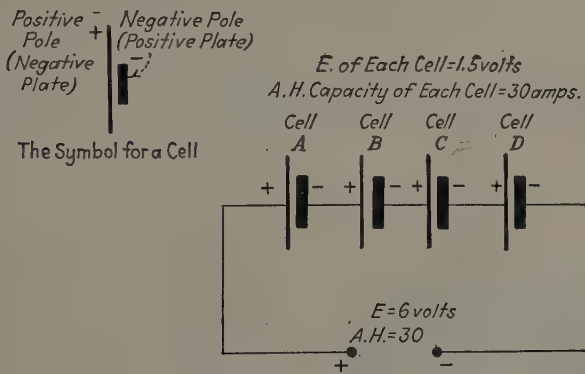


FIG. 39.—Cells in series.

one cell, and so on; the more cells that are connected in series, the greater will become the resistance. Furthermore, whenever a number of cells are connected in series they are called a "battery"

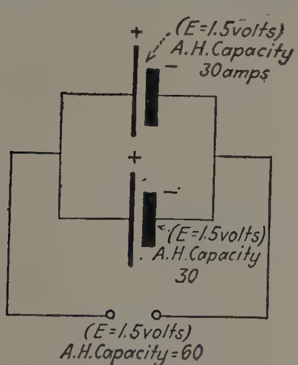


FIG. 40.—Cells in parallel.

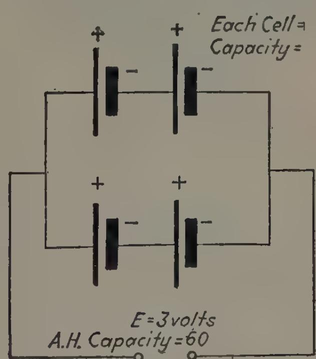


FIG. 41.—Cells in series-parallel.

and similarly when a group of the latter are connected in series they are called "batteries."

The Ampere-hour Capacity of a Cell.—The ampere-hour capacity of a cell is proportional to the area of the active materials

exposed to the electrolyte. Hence, it follows that the capacity of a cell depends also on the number of plates connected in parallel, their character, the rate with which they are discharged, and also the temperature. The proper working temperature should be in the vicinity of 70° F. and must never exceed 110° F.

The ampere-hour capacity of a dry cell is about 30 amp.-hr., therefore, if it were desired to increase the capacity, a larger cell could be designed; this is not practical, therefore, a number of cells could be placed in parallel to increase the ampere-hour capacity (Fig. 40).

If it were necessary, however, to increase the voltage and capacity then a number of cells could be connected in series-parallel (Fig. 41).

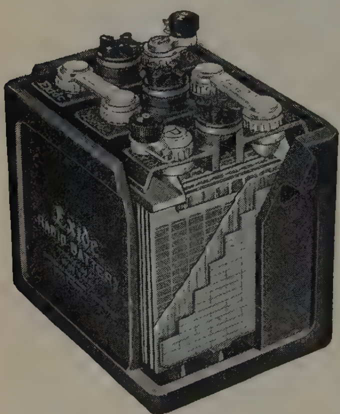


Fig. 42.—Cross-section of lead-plate storage cell.

The series combination will give the necessary voltage increase and the parallel combination will give the necessary capacity or ampere-hour increase.

The Lead-plate Storage Cell.—The essential difference between the primary cell and the secondary cell (storage cell) is that the former, once it has been completely discharged, requires a renewal of elements (plates and electrolyte) while the latter may be charged without renewing the plates or electrolyte.

Storage batteries used in radio installations are divided into two general classes: the lead-acid cell and the Edison or nickel-iron-alkaline cell. The lead cell, a cut of which is shown in Fig. 42, will first be considered.

Lead Cell.—A detailed view showing the various parts of the lead cell is shown in Fig. 43.

Storage cells produce electricity as a result of chemical action after they have been subjected to an initial charge. This action takes place between the active material of the positive and the negative plates and the electrolyte, which, in the case of the lead cell, is a dilute solution of sulphuric acid. Examine care-

fully the various parts of the cell, noting the way in which the parts are assembled.

The *active material* of the positive and the negative electrodes is pasted on a grid made up of a lead-antimony alloy. A full cut of the positive and negative plates is shown in Fig. 43.

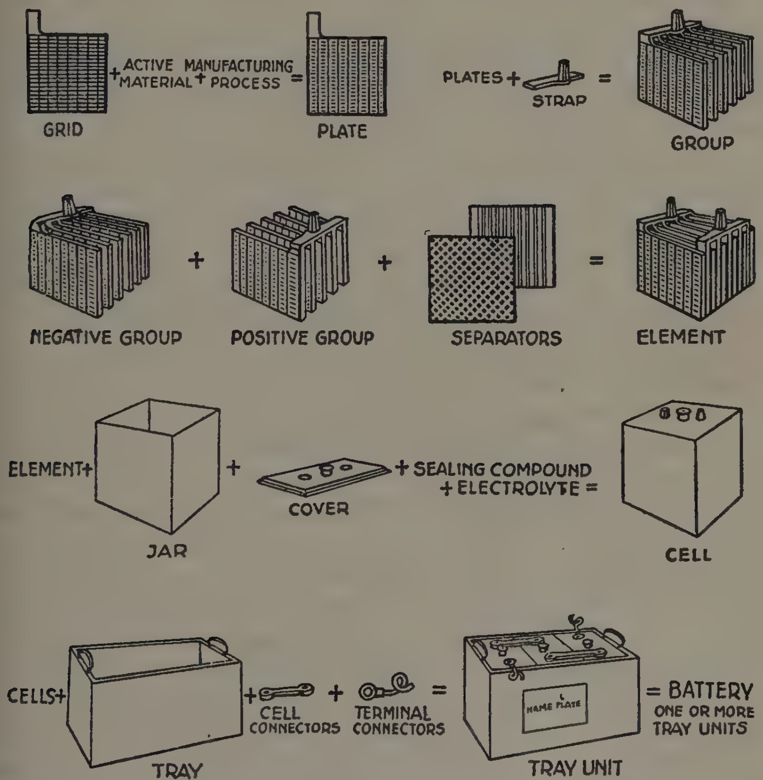


FIG. 43.—Parts and assembly of a typical portable storage battery. (Lead-sulphuric-acid type.) Sections of lead cell.

Positive Plates.—The positive plate consists of a grid filled with lead peroxide (PbO_2) which is the active material. Upon exposure to air it turns a dark reddish color.

Negative Plate.—The negative plate consists of a grid with an active material of pure spongy lead (Pb). This negative plate is gray in color.

Construction of Cells.—In constructing cells, a number of these plates are fastened together. When so fastened the group of plates is called an element. There are both positive and negative elements. There is usually one more plate in the negative element group than there is in the positive group, so that when the elements are interlocked, the two outside plates are negative.

In order to insulate the positive plates from the negative plates, there is inserted between the plates a wooden or rubber separator, together with a perforated rubber separator. Both positive and negative elements and the separators are inserted in a hard-rubber jar.

There is a space between the bottom of the elements and the bottom of the jar. This space makes room for any active material which may become loosened from the grids and fall. The cell must be taken apart and all loose sediment cleaned out as often as is necessary, this depending upon the usage of the particular cell. Generally speaking, however, cells used on shipboard as a source of auxiliary electrical power for the radio transmitter should be thoroughly overhauled annually.

Parts and assembly of a typical storage battery are shown in Fig. 43. This shows graphically the various steps of manufacture starting with the grid. The active material is pasted on the grid to make up the plate. The plates are then fastened together with straps. Plates so fastened together are called a "group." All the positive plates go to make up one group and all the negative plates make up the other group. There are, therefore, two groups which are interlocked. Wooden and perforated rubber separators are placed between the successive plates to insulate them one from another. The two interlocked groups together with separators are called the "element." The elements are then placed in a hard-rubber jar, which has a hard-rubber cover. The cover is fastened by means of sealing compound. The cover has three perforations; the opening in the center is used for admitting electrolyte (liquid) and the two outer openings are those through which the positive and the negative group terminals come through. Cells are mounted together in a strong supporting box. They are then called a "tray of cells." The cells are then connected in series by means of cell connectors. For connecting

battery trays terminal connectors are used. A number of trays mounted together are called a "tray unit," and one or more tray units go to make up a battery.

Electrolyte.—The electrolyte used in lead cells is made by mixing sulphuric acid (H_2SO_4) and water (H_2O). The amount of each depends upon the specific gravity desired, which in turn depends upon the type of cell used. For portable batteries, such as are used in radio, the specific gravity of the electrolyte is approximately 1.270 before the battery has been discharged. This is in the proportion of 7 parts water to 2 parts acid. In mixing new electrolyte always pour the acid into a large jar of pure distilled water. Never pour the water into the acid as this produces a violent chemical action resulting in heat, which may cause the compound to splash, and injure anything with which it might come in contact.

The electrolyte should always be kept to a level of ½ in. above the top of the plates. To maintain this level, never add anything but pure distilled water, for two reasons: *First,* acid does not evaporate and therefore the same amount of acid will always remain in the cell, either in the electrolyte or combined with the active material of the plates. Acid may be lost, however, by excessive spraying of the cells, and even with normal spraying acid is generally lost which must be, at some time, replaced. Operators, however, are usually prohibited from adding acid. *Second,* water not distilled may have in it impurities which would cause internal local action within the plates.

The only occasion when more acid would be added is when some of the electrolyte is spilled out and cannot be recovered. This might easily happen during shipment, overhauling, or installation, and may also be possible on board a vessel when in a rough sea.

When it is necessary to add acid to the electrolyte, it must never be added pure. A solution of equal parts of acid and distilled water should be kept on hand for this purpose.

The *specific gravity* of a substance or liquid is the weight of a given volume of that substance or liquid as compared with an equal volume of distilled water. Distilled water has a specific gravity of 1, or unity, and materials that are heavier than distilled water, liquids, or solids, have a specific gravity greater than unity. Chemically pure sulphuric acid has a specific gravity of 1.840

or, in other words, it has 1.840 times the weight of a given volume of water.

Hydrometer.—The hydrometer measures the specific gravity of a liquid and is used to measure the specific gravity of the electrolyte. It consists of a glass tube from 3 to 5 in. long, having a small bulb on one end filled with shot or mercury so that it will sink in a perpendicular position when put in a liquid. On the other end are graduations which make up the gravity scale. The

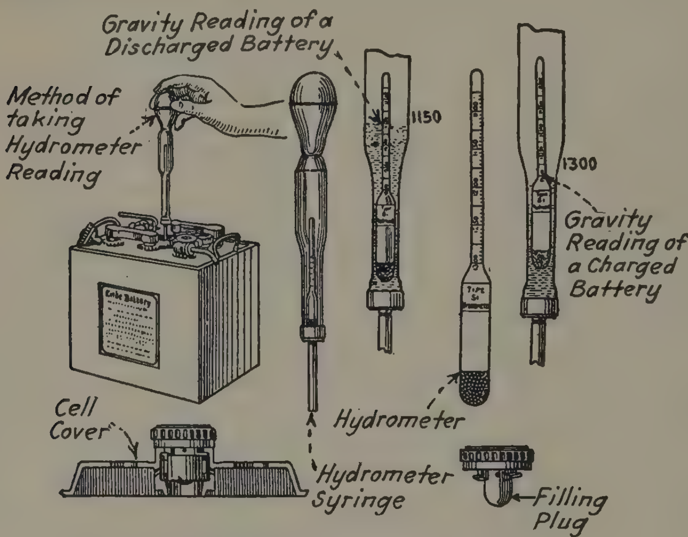


FIG. 44.—Hydrometer and parts.

portable type, used with radio equipments, is set in a glass tube an inch or so in diameter with a rubber bulb on one end to draw up the electrolyte. On the other end is a rubber tube which conveniently fits into the opening in the top of the cell. Figure 44 shows the hydrometer in detail.

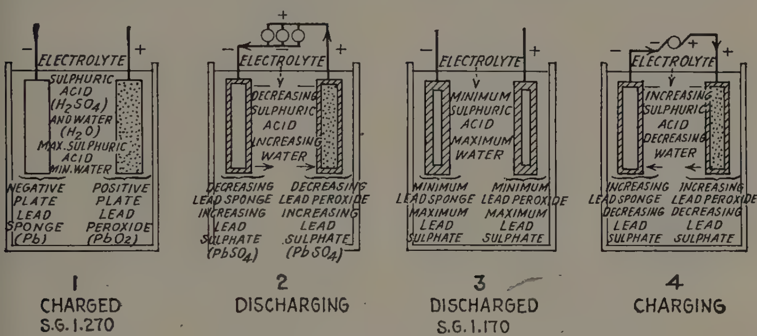
Chemical action is what produces the electromotive force in storage batteries. This action takes place between the electrolyte (liquid) and the active material of the plates (solid). If a fully charged cell is placed in a circuit and discharged, it undergoes a chemical change. This change may be easily understood if Fig. 45 is studied. When a cell is fully charged, its specific

gravity is 1.270, or above, which shows that the liquid has a maximum amount of acid in it. During the period when a cell is being discharged, the acid is leaving the electrolyte and combining with the active material of the plates.

When a cell is fully discharged there is very little acid left in the electrolyte, in fact, not enough acid to cause the chemical action necessary to produce electromotive force.

Chemical action in a lead cell during one cycle of discharge and charge is graphically illustrated in Fig. 45. Four periods exist,

CHEMICAL ACTION IN A CELL ON CYCLE OF DISCHARGE AND CHARGE



CHEMICAL EQUATION

CHARGED CELL			DISCHARGED CELL		
NEGATIVE PLATE	POSITIVE PLATE	ELECTROLYTE	NEGATIVE PLATE	POSITIVE PLATE	ELECTROLYTE

$$2Pb + 2PbO_2 + 5H_2SO_4 + 7H_2O + Pb + PbSO_4 + PbO_2 + PbSO_4 + 3H_2SO_4 + 9H_2O$$

FIG. 45.—Chemical action in a lead cell.

showing conditions in the cell from the time it is fully charged until it has been completely discharged and is put on charge again.

Period No. 1, which is the charged cell, shows that the electrolyte is of the proper specific gravity, at which time all of the acid is mixed with the water and there is a maximum amount of acid in the electrolyte. The negative and positive plates are in their natural condition having only their active material (sponge lead and lead peroxide, respectively) on them. The cell is as assembled, no chemical changes having as yet taken place.

Period No. 2 shows the cell as it starts to discharge. It shows the acid leaving the electrolyte and going into and combining with

the active material of the plates. As it does this, it reduces the positive and the negative plates to lead sulphate, decreasing the sponge lead and lead peroxide. This continues until nearly all of the acid has gone from the electrolyte into the active material of the plates. The specific gravity becomes lower as the acid leaves the water. To determine the state of discharge, a hydrometer reading may be taken. In the lead cell, when so much acid has left the water that the specific gravity is down about 100 points from the charged reading, the cell is said to be discharged.

Period No. 3 is the discharged cell. Here, in the electrolyte are a minimum amount of acid and a maximum amount of water. The porous, active material is clogged up and coated with lead sulphate and chemical action ceases. The plates are now sulphated but not to a serious degree. This sulphate is removed by charging.

Period No. 4 shows the cell on charge. The chemical action is the reverse of Nos. 1, 2, and 3. The acid is being driven out of the active material of the plates back into the water (electrolyte). The sulphate is changing back to its original form of sponge lead and lead peroxide. The cell is not fully charged until all of the sulphate is gone from the plates. The life of the lead cell is often shortened because the cell is only given a partial charge; all of the sulphate is not removed and it becomes hard. This clogs the porous active material so that the acid cannot make contact and the result is a lessening of the chemical action between the electrolyte and the plates. This decreases the capacity of the cell.

For those students versed in chemistry, the chemical equation given at the bottom of the chart will prove helpful.

Charging.—In order that this cell may again be useful, it is necessary to restore the electrolyte and plates to their previous fully charged condition. To accomplish this, the acid must be driven out of the plates and back into the electrolyte. This is the whole object of charging and may be done by connecting a cell in a direct-current circuit as shown in the diagram (Fig. 46). Note that the positive plate (+) is connected to the positive side of the line and, likewise, the negative plate (−) is connected to the negative side of the line. The charging voltage or, in other words, the electricity flowing into the cell, must be of higher

pressure value than that of the cell or cells under charge in order to overcome the resistance of the elements of the cell. For example, if a single cell has a voltage of 2.1, the charging voltage should average about 2.8 volts. If ten of these cells were connected in series, the resultant battery discharging voltage would be 21 volts, or ten times the voltage of one cell. The charging voltage would then have to be 28 volts.

When the electricity is flowing into the cell, work is being done, forcing the acid out of the plates and back into the electrolyte. This work, or the energy expended in doing this work, becomes less and less as the charge proceeds until all of the acid has been restored to the electrolyte, at which time there is no more work to be done; hence, the battery is charged. It is advisable, therefore, that the current be of greater value at the beginning of a charge than at the finish. If the current is kept at the same rate during the whole charge, as is done in a good many radio equipments, the cells will start gassing long before the charge is finished. This gas is the result of an excess current flowing through the cell. For large storage-battery equipments, it is necessary to reduce the current as the charge proceeds. When a current flows, energy is expended. This energy at the beginning of a charge is used to drive the acid out of the plates and, as this particular kind of work becomes less, it expends itself by decomposing the electrolyte into a gas. For this reason, when a cell starts gassing it is a sign of progress of the charge. Storage batteries used with radio equipments are usually allowed to gas from 2 to 4 hrs. before the charge is completed.

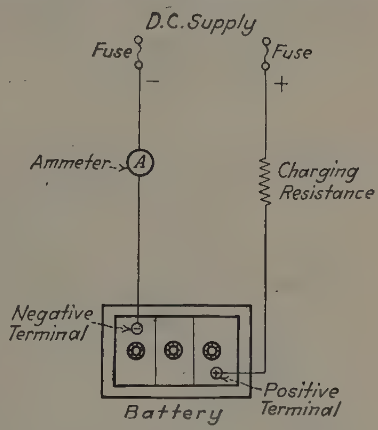


FIG. 46.—Simple charging circuit.

Wrong Charging Polarity.—It is very important that the positive side of the charging line be connected to the positive side of the battery to be charged. It is readily seen that, inasmuch as the object of the charge is to reverse the chemical action which

took place during discharge, the current must flow in the opposite direction to the way it flowed during discharge. If, by accident, the polarity of the charging line is reversed, the chemical action which took place during discharge will be continued and the effect will be a sulphation of the plates, possibly a buckling of the plates and a loosening of the active material from the grid.

The polarity of the charging line may be determined by a direct-current voltmeter, the terminals of which are marked with the positive (+) and the negative (−) signs, and the dial pointer will tend to read backwards if not connected properly across the line. The side connected to the positive side of the voltmeter is,

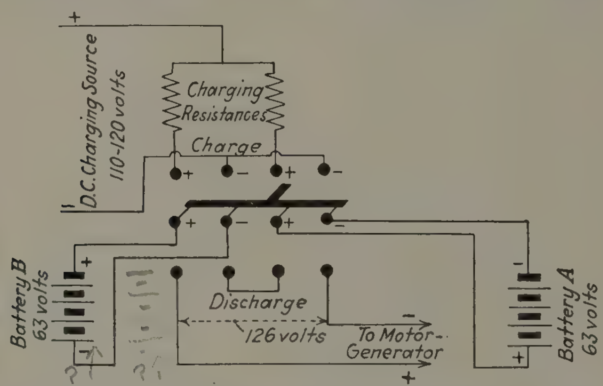


FIG. 47.—Method of charging and discharging a bank of batteries.

obviously, the positive side of the line and, therefore, the other side is the negative side.

If a voltmeter is not available, a glass may be filled with plain water into which is put some ordinary salt and the terminals of the line immersed in it. Bubbles will appear at the negative side of the line. Great care must be taken not to bring the terminals together, as a complete short-circuit of the line will result with the consequent result of blowing fuses and possibly damaging some part of the line or burning the hands from the heavy flash which will occur at the point of contact.

Series and Parallel Charging.—The voltage of the charging line must always be greater than the voltage of the bank of batteries to be charged. If the charging generator gives 100 volts, therefore, as ship generators frequently do, it would be

necessary to lower the voltage of the radio battery bank which is usually 110 volts or higher. This may be done by cutting the bank in half and connecting the two sections in parallel. When this is done, and it is done on all ship equipments, each section is labeled *A* and *B*, respectively. During discharge, they are in series; during charge they are connected in parallel. This is done by means of a switch, as shown in Fig. 47, which shows the charging circuit employed on modern equipment.

Ventilation is very important when cells are being charged, to allow the forming gases to escape. The rubber plugs should be unscrewed from each cell, the wooden covers removed from the trays, and a window of the room in which the batteries are located left open.

Sulphation.—As explained before, the active material of the plates is reduced to sulphate as discharge continues. If this action is carried too far, by overdischarge, or if sulphate is allowed to accumulate by repeated undercharging, sulphation will take place. A battery is *sulphated* when the pores of the active material are clogged up with hardened sulphate.

Sulphation may also be caused by allowing the cells to stand discharged for some length of time; by neglecting trouble in individual cells; by replacing evaporation with electrolyte instead of water, thereby restoring specific gravity by adding acid, rather than by driving it out of the active material of the plates by charging. Sometimes the cause of sulphation is an internal short-circuit or the failure to replace a broken jar.

Sulphation may be recognized as the trouble when a battery does not give its rated capacity after a normal charge.

The remedy for ordinary cases of sulphation is to put the battery on charge for several hours more than is necessary under normal conditions, then partly discharge, repeating the operation several times until normal conditions return.

In particularly bad cases, it may be necessary to send the battery to a service station where the charging apparatus is large enough to supply the flow of extra-heavy current at the commencement of the charge, which can be reduced or tapered down as the charge proceeds. In no case should the temperature of the cells be allowed to exceed 110°F., the current being reduced when this heat is registered.

A sulphated battery is restored when the specific gravity of the electrolyte is back to normal.

Care and Management.—To avoid sulphation, charge the cells every 2 weeks at least and keep the electrolyte at the proper height above the plates, which is about ½ in. above the top of the plates.

A bank of batteries should never be overdischarged. Neither should they be overcharged except in case of an equalizing charge. Take frequent hydrometer readings and both of these evils can be avoided.

It is a good thing to record in a blank book each month the hydrometer readings of each cell. The behavior of all cells can be studied over a period of time.

Any cell or cells not giving the proper hydrometer readings, or which gas more slowly than the rest, should be inspected.

The *voltage* of the lead cell is not a good indication of its state of discharge and the cells may recuperate after not being used and give a fairly high open-circuit or no-load voltage reading. The voltage readings are, therefore, valuable only if taken while the battery is discharging at the normal rate. This may be done by starting the motor generator set for which the battery is provided to drive in case of an emergency.

All of the instruments necessary in order to care for a battery properly are provided on modern charging panels, except the hydrometer, which obviously is used directly with the cells. It will, of course, be necessary to have a portable voltmeter if individual cell voltage readings are to be taken.

The voltages and specific gravity of the charged and discharged lead and Edison cells are summarized at the end of this assignment.

Important

Don't bring open flames near a charging cell. Gas is escaping.

Don't allow the electrolyte to get low.

Don't neglect to charge regularly.

Don't neglect to take regular hydrometer readings.

Add nothing but distilled water to the electrolyte unless it has been spilled, in which case a small quantity of acid might be added.

Remove vent caps and tray covers when charging.

Be sure charging polarity is correct by observing the readings of the voltmeter on the charging panel.

Charging is generally complete in the lead cell when gassing has gone on for from 2 to 4 hr. Hydrometer readings will tell.

Keep the outsides of the battery boxes absolutely clean.

Don't charge or discharge at too high a rate.

Capacity.—The capacity of the storage battery is rated as so many ampere-hours; this means the battery will give this amount

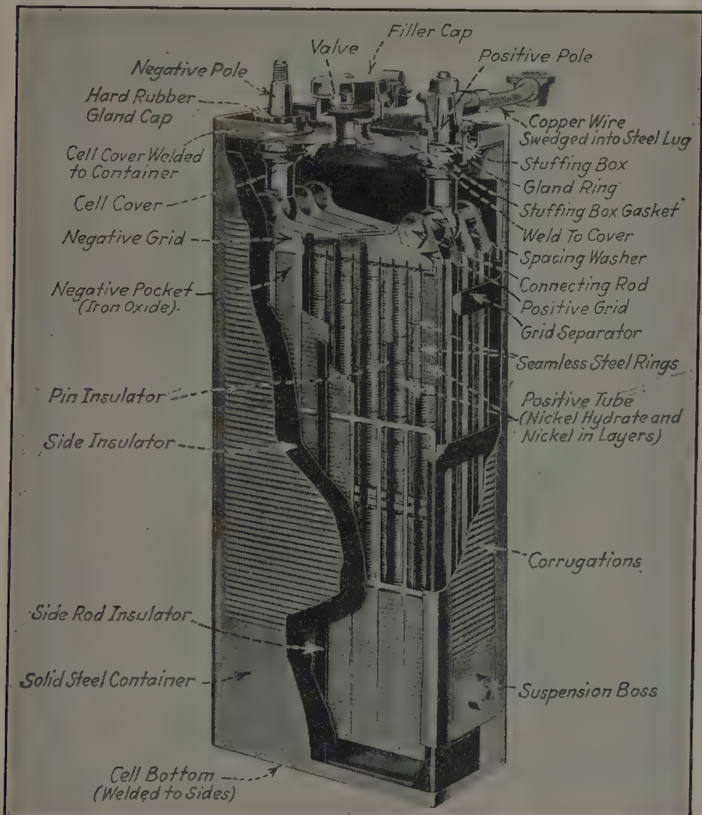


FIG. 48.—Cross-section Edison cell.

of current multiplied by the time of discharge. As an illustration; the 60-amp.-hr. battery will give 1 amp. for 60 hr.; 2 amp. for 30 hr.; 3 amp. for 20 hr., etc. The capacity of a battery is indicated on a nameplate which is attached to the battery tray. The charging rate is also given together with other data, which varies depending on the manufacturer.

The normal charge and discharge rates are the safe maximum currents that can be sent into the cell on charge and taken from the cell on discharge, and are determined by the makers of the cell and indicated on the name plate.

Cleanliness must not be overlooked in the maintenance of all batteries. If dirt or spilled acid is allowed to collect, trouble

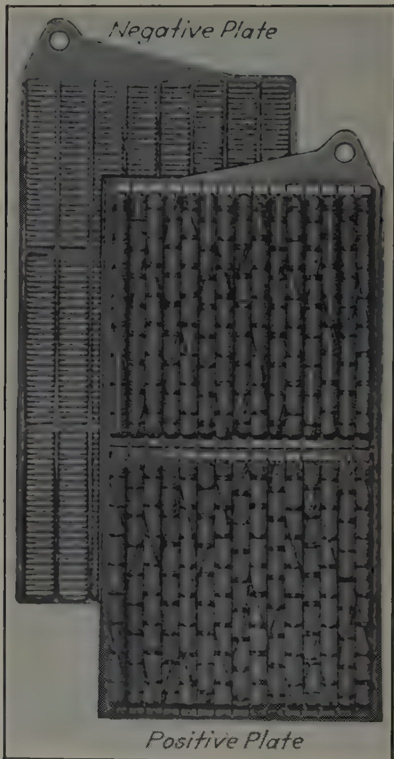


Fig. 49.—Plates of an Edison cell.

will follow. The tops of the cells should be wiped off with a cloth moistened with a weak solution of bicarbonate of soda to neutralize the acid, and then sponged with fresh water. All trays should be washed with an alkali and then painted with an asphaltum compound. Cell terminals should be cleaned and connections should be taken apart and scraped to insure good

contact. All signs of corrosion should be scraped from the metal parts of the trays.

The *Edison cell,* as the nickel-iron-alkaline cell is called, is of a very different type of construction than the lead cell; they have nothing in common. Figure 48 shows the Edison cell.

Positive Plate.—The positive plate consists of heavily nickel-plated, perforated, steel tubes, arranged in rows and filled with alternate layers of nickel-hydroxide and exceedingly thin flakes of pure nickel, as shown in Fig. 49.

Negative Plate.—The negative plate consists of a grid of nickel-plated, cold-rolled steel holding a number of rectangular pockets filled with powdered iron oxide, as shown in Fig. 49. In Fig. 50 is shown the way in which the negative and the positive plate elements are interlocked and held in place by the end separators. Note that the end plates are negative.

FIG. 50.—Plate assembly Edison cell.

Separators.—The plates are separated by narrow strips of specially treated hard rubber which is not injured by the electrolyte. The end insulator is provided with grooves that take the edge of the plates, spacing and insulating them from the steel container.

Electrolyte.—The electrolyte consists of a 21 per cent alkali solution of potassium hydrate in distilled water with a small percentage of lithium hydrate having a specific gravity of 1.200. The electrolyte does not vary in density during charge and discharge, therefore, hydrometer readings are unnecessary. The cells are assembled into a battery in strong side suspension trays.

The *container* is made of cold-rolled, corrugated, nickel-plated sheet steel. The present form of Edison cell has a separator valve which permits the escape of gas when the cell is charging, but prevents spraying, evaporation, the spilling of the elec-

trolyte, and the entrance of impurities to the inside of the filling aperture. There are only three perforations in the can cover.

Care and Management.—The care required by the Edison cell is limited to such matters as the addition of distilled water, to make up for evaporation losses and the renewal of the electrolyte when its specific gravity falls below 1.16 after a full charge. The outside of the battery must be kept clean and the trays given an occasional recoating of alkali-proof paint.

The Chemical Reaction in an Edison Storage Cell.—During the period of charging, when the positive side of the charging voltage is connected to the positive terminal of the Edison cell, the current which is flowing through the cell produces an oxidation of the positive plate and a reduction of the oxide in the negative plate. This may be defined as *a chemical reaction in which the negative plate of iron oxide is reduced to a lower state of oxide* through the medium of the alkaline solution which acts merely as a conveyor and thus tends to add oxygen to the positive plate. The nickel hydrate, as a result of this action, becomes highly oxidized.

Upon discharging the cell the oxidized plate of nickel hydrate is lowered to a lower state of oxide and the negative plate is again restored to its original higher state of oxide. In other words, the chemical action in an Edison cell may be simply defined as *an oxidization of the positive plate during charge and a considerable deoxidization upon discharge.* The electrolyte merely acts as a conveyor and, therefore, does not change. The chemical formula for the charge and discharge of the Edison cell is as follows:

$$2Ni(OH)_3 + Fe \underset{\text{Charge Reads Right To Left}}{\overset{\text{Discharge Reads Left To Right}}{\rightleftarrows}} 2Ni(OH)_2 + Fe(OH)_2,$$

Chemically the active materials and electrolyte are expressed as follows:

$Ni(OH)_3$ and Ni represents the active material of nickel hydrate and flake nickel.

Fe_2O_3 and Fe represents the iron oxide and metallic iron.

KOH represents the alkaline electrolyte.

$Li(OH)_3$ represents the small amount of lithium hydrate.

Charging.—The charging should never be done at less than the 7-hr. rate, and may be boosted to high rates for brief periods so long as the temperature of the cells does not rise above 115° F.

Efficiency.—The efficiency of the Edison cell is about 75 per cent of that of the lead cell because of the higher internal resistance of the cell.

Capacity.—The capacity of the Edison cell increases with use and it is guaranteed to give full capacity for four years.

Advantages and Disadvantages of the Two Types of Cells.—These may be summed up as follows: The principal advantage of the lead cell is its high efficiency and ability to maintain rated capacity under sudden heavy loads and low first cost. The disadvantages are: excessive weight, structural weakness of parts, corrosive nature of the electrolyte and fumes, loss of capacity, shedding of active material, exacting and incessant care necessary for successful operation, fracture and buckling of plates, sulphation, internal discharge, and high installation and maintenance costs.

The advantages of the Edison cell are: increase of capacity with use, simplicity of care required, ease of interconnecting cells, steel preserving electrolyte and lack of corrosive fumes, durability and sturdiness of cell structure, low weight per unit of capacity, ability to withstand short-circuit, absence of sulphation, no buckling of plates, no loosening of sediment, immunity from injurious effects of overcharge, and low maintenance cost.

The disadvantages of the Edison cell may be summarized as follows: high initial cost and comparative low efficiency due to high internal resistance. This latter disadvantage means that the Edison cell will not maintain a high capacity under sudden heavy loads. It is, therefore, unsuited for use with automobile starters where the load is sudden and extremely heavy. Sudden heavy-load conditions such as this are not met with in radio equipments.

Summary of Data on Lead and Edison Cells

		Edison cell	Lead cell
Voltage	Charged	1.20	2.10
	Discharged	0.9	1.75
Specific gravity	Charged	1.200	1.270
	Discharged	1.160	1.150
Charging voltage per cell	....	1.85	2.4

Note.—The discharged gravity reading of 1.160 is only obtained when the electrolyte has considerably weakened due to aging or evaporation of the water. When the Edison cell is new, the discharge specific gravity reading does not vary and usually stays in the vicinity of 1.200. This is due to the fact that the electrolyte does not enter into combination with any of the active materials as it does in acid cells. Hydrometer readings are, therefore, unnecessary.

Questions

1. How can an e.m.f. be generated by chemical action?
2. Draw a diagram of a simple chemical cell.
3. What is meant by local action?
4. Describe the construction of the dry cell.
5. What determines the voltage of any cell?
6. What determines the ampere capacity of a cell?
7. What would be the effect upon the voltage and amperage of two cells connected in parallel? In series?
8. What are the active materials of the lead-plate storage cell?
9. What are the active materials of the Edison cell?
10. What is the difference between the primary and the secondary cell?

CHAPTER VIII

ELECTRICAL METERS

Galvanometer.—The galvanometer is an electromagnetic instrument for detecting and measuring the magnitude and direction of small electric currents.

This instrument works on the principle that a magnet placed in the vicinity of a current-carrying conductor tends to arrange itself in a certain position with relation to the magnetic field surrounding the conductor. In some types of galvanometers the magnet is movable inside a stationary coil and in others the magnet is stationary and the coil, to which a pointer is attached, moves between the coils of the magnet. As a simple experiment, the student may hold an ordinary, camper's type of compass over a simple solenoid consisting of about 30 turns of annunciator wire, the terminals of which are connected to a dry cell. As soon as it is placed in the magnetic field the north pole will seek a certain position and the south pole the direct opposite. Now reverse the connections of the coil to the dry cell; the compass will immediately reverse itself, due to the reversal of the current flow in the solenoid.

Galvanometers can be made very sensitive, and for this reason are used mostly in laboratory work or in classroom demonstrations.

Voltmeter.—The voltmeter, as well as all other electromagnetic measuring instruments, works on the principle explained for the galvanometer. A drawing showing the principal parts of a voltmeter is shown in Fig. 51. In the type shown, the coil is movable and the magnet stationary. This is called the "moving-coil" type of meter. It is somewhat similar in construction to a simple electric motor; it has field poles and an armature which moves between the field poles. The terminals of the moving coil are connected to the current to be measured. As the current flows through the winding, it sets up a north and a south pole in the coil,

which tends to set itself in a certain position with regard to the magnetic poles. It is this tendency which makes it possible to use it as a measuring instrument. The voltmeter is always connected in shunt to or across the source of e.m.f. or any portion of the external circuit in which the *IR* drop is to be measured and never in series with the source and external circuit. No harm will come to the meter if it is connected in series with the line due to its series resistance, but it will not give a proper reading.

To the movable coil of the meter is attached a pointer which moves over the scale of the instrument. This scale may be calibrated to read any voltage value depending upon the design of the

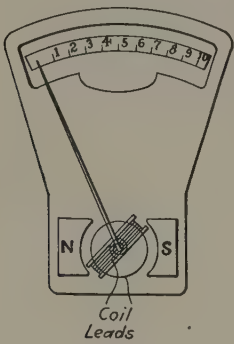


Fig. 51.—A simple voltmeter.

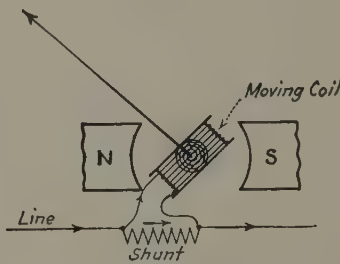


Fig. 52.—Principle of the ammeter.

meter, which is mainly dependent upon the value of its series resistance.

Because the voltmeter must be connected across the line it must have a very high resistance to prevent a short-circuiting of the current. This resistance is provided in the form of a resistance coil which is connected in series with the moving coil and is located inside the meter case. A small spring fixed to the shaft of the moving coil opposes the movement of the pointer over the scale and forces the pointer back to zero position as soon as the current ceases to flow.

Ammeter.—The ammeter is essentially of the same construction as the voltmeter except that it is a low-resistance instrument and, therefore, the resistance coil used as part of the voltmeter is not used with the ammeter. The ammeter is always connected

in series with the load. If it is connected across the line it will be ruined immediately as the low-resistance movable coil will be burned up. Great care must always be exercised in connecting meters to a circuit as several hundred dollars' worth of damage may be done in a fraction of a second if a wrong connection is made.

Ammeters can be built for only very small currents when using the movable-coil type. In order that large currents may be measured a unit known as a "shunt" is provided. This is connected across the connecting posts of the instrument in the

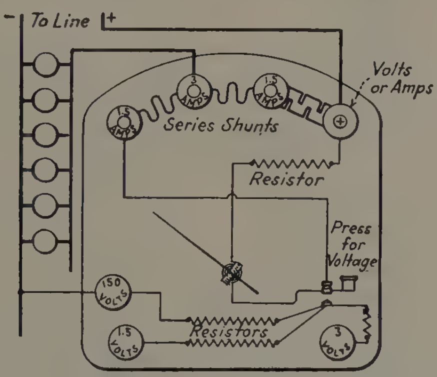


Fig. 53.—Diagram of Weston direct-current voltammeter, model 280.

interior and allows the larger part of the current in the circuit to flow through it (Fig. 52). These are called internal shunts.

Only a small part of the actual current indicated on the scale of the meter actually flows through the meter. Special shunts are provided for each type of meter and only the shunt provided with a meter may be used with it. These are called external shunts and should always carry the serial number of the meter with which it is to be used. The connecting leads of the shunt are of a certain length, determined when the meter is calibrated with that particular shunt, and must not be changed. If the length of the lead is changed at all the meter will not read correctly.

The ammeter and voltmeter are parts of every transmitter circuit and it is important that their operation and how they should be connected in the line be understood.

Wattmeter.—The wattmeter reads directly on a scale the exact wattage expended in the circuit. For direct-current circuits, this is the product of the volts times the amperes but in the alternating-current circuit, due to a characteristic known as the power factor, the wattage in this latter circuit is not exactly the product of the volts times the amperes. The wattmeter, however, compensates for this difference and is calibrated to give a true reading.

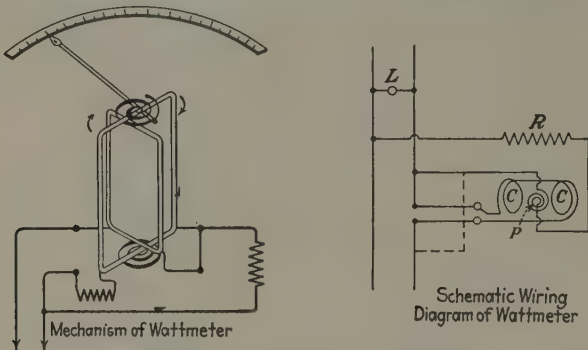


Fig. 54.—Principle of the wattmeter.

The wattmeter has two coils—one stationary and one movable. They are known as the "current" coil and the "voltage" or "pressure" coil. The current coil is fixed in position and the pressure coil is movable. The mechanism of the wattmeter is shown in Fig. 54. Note that the voltage coil is connected

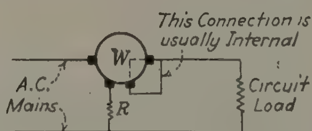


Fig. 55.—Wattmeter connection to a circuit.

directly across the line, as with the voltmeter. The wattmeter has four connecting posts and is connected in the circuit as shown in Fig. 55. Some types of wattmeters have only three connecting posts.

Frequency Meter.—The frequency meter reads directly on a scale the frequency of the alternating current generated by the alternator. There are two common types of frequency meters, one being known as the Hartman and Braun vibrating—reed

type frequency indicator, and the other as the Westinghouse frequency indicator, induction type. The Hartman and Braun vibrating-reed type indicates the frequency through a series of tuned steel rods which vibrate before a magnet. This type has been replaced in modern apparatus by the inductor type which reads the frequency directly by a pointer moving over a scale. This type of frequency indicator may be understood by referring to Fig. 56. It is operated on the induction principle. Two coils *A* and *B* act on the disc *G* and are balanced against each other. In series with coil *A* is a non-inductive resistance *H*, and the

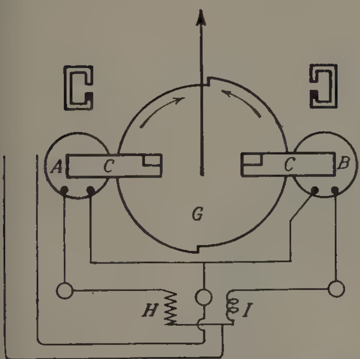


FIG. 56.—Principle of frequency meter.

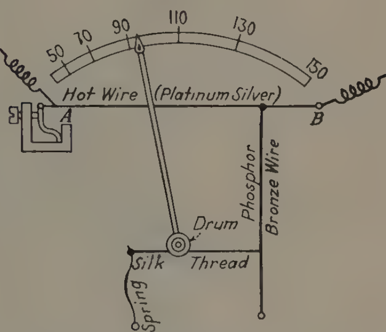


FIG. 57.—Principle of hot-wire ammeter.

coil is in series with a reactance *I*. The amount of current flowing through the reactance will vary as the frequency changes: an increase in frequency causing an increase in inductive effect. The torque exerted on the disc by each coil is proportional to the square of the current and the frequency. The torque of the non-inductive element, therefore, will increase with an increase in the frequency and the other will decrease, owing to the decrease of current flowing through it because of the greater self-induction. The disc will, therefore, move until equilibrium is established. Note that the disc is not absolutely round but slightly spiraled: this is so that the side of the disc which is influenced by the inductive coil will present more surface to be acted upon as the torque exerted by this coil becomes less with the increase in frequency.

Hot-wire Ammeter.—A much used type of hot-wire ammeter is the Hartman and Braun meter shown in Fig. 57. The hot-wire meter will operate on either direct or alternating current. It consists essentially of a special resistance wire stretched between two points, which is affected in its length by its temperature. Heating the wire causes it to slacken, and this in turn affects the pointer as shown. The sag in the wire may be adjusted by the adjusting screw to the left. The drawing is fully labeled and should be easily understood.

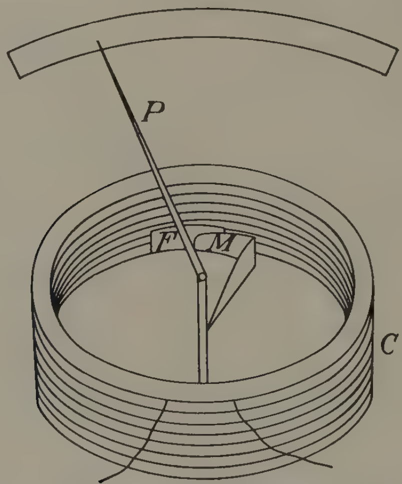


Fig. 58*a*.—Principle of alternating-current voltmeter.

Alternating-current Meters.—The permanent magnet type of voltmeter and ammeter explained before cannot be used for low frequency alternating-current measurements. For this purpose there are two general types in use; the moving vane type and the inclined coil type. These are shown in Figs. 58*a* and *b*. The strip F is magnetized by the coil C. It also magnetizes the strip M which is attached to the pointer P moving over a calibrated scale. The strip F tends to repel the strip M as the magnetization takes place and this effect increases with the amount of voltage, or if the meter is an ammeter, the current flowing through the coil C. This causes the pointer to indicate a value on the scale.

In the inclined-coil type the coil affects a metal vane mounted on a shaft as shown. A pointer which passes over a scale is fastened to the shaft which holds the vane.

Instruments of these two types, if they are to be used as ammeters, have the coils wound with heavy wire, while if they are to be used as voltmeters, the coils are wound with many more turns of fine wire and a resistance connected in series with the coil, as with the direct-current voltmeter.

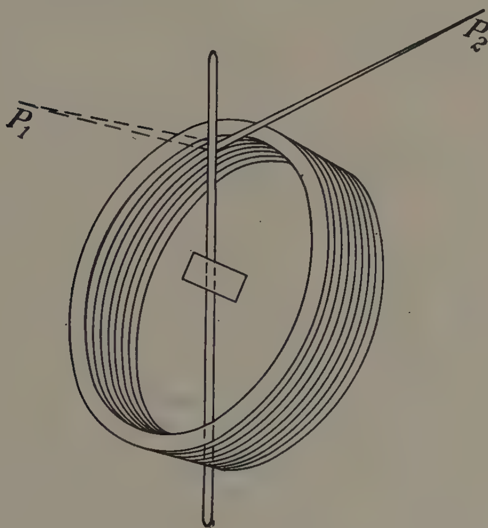


FIG. 58*b*.—Principle of alternating-current voltmeter.

The scales of direct-current instruments (voltmeter and ammeter) are evenly divided, from zero to maximum, each division being equally spaced from the next. This is a mark of the direct-current instrument of the electromagnetic type. The alternating-current scale, on the other hand, is not evenly divided, the units increasing with the square of the value. For example, the spacing on the scale between units 3 and 4 is approximately one-fourth the space between units 15 and 16.

The Thermocoupled Ammeter.—This type of ammeter is one of the most efficient types used in the measurements of currents

at high frequency. Figure 59 illustrates the principle used in this type of meter.

The theoretical function is described briefly as follows: If two wires of dissimilar metals are welded together and subjected to heat, a molecular disturbance is generated at the point of junction where the two wires are exposed to the heat. If, therefore, the two free ends of the wire are connected to a very sensitive indicating device, such as a galvanometer, a current may be made to flow through the meter and result in a deflection. From this it will be noted that the e.m.f. which is generated at the thermo-junction is a direct function of the heating effect and, therefore, the heating will be proportional to the square of the current.

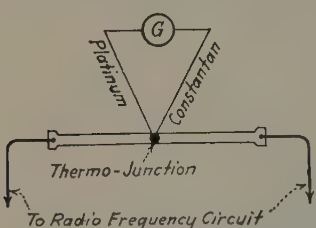


FIG. 59.—Principle of thermoammeter.

If the heavy wire in Fig. 59 is connected to a high-frequency current, there will result a deflection in the galvanometer which is also proportional to the square of the radio frequency current.

With this system of current indication extremely heavy currents can be measured at radio frequencies without actually passing these currents through the galvanometer.

The two dissimilar wires which have been found to give the best results as a thermocouple are very thin wires of steel and constantan. Another thermocouple made of very fine wires of constantan and manganin may also be used as thermo-elements.

Another type of extremely sensitive junction characteristics has been developed in which the dissimilar metals are of tellurium and constantan. This type of thermocouple when connected to a very sensitive galvanometer has been found to generate twenty to thirty times more e.m.f., for the same temperature, than the other of the types previously mentioned.

Questions

1. Describe the simple galvanometer.
2. How does the galvanometer function?
3. What is the difference between the voltmeter and the ammeter?
4. How does the alternating-current voltmeter function?
5. Describe and explain the operation of the thermoammeter.

CHAPTER IX

CHARGING PANELS AND PROTECTIVE EQUIPMENT

The Navy Standard Panel.—Figure 60 is a wiring diagram of the Navy Standard type S.E.-839 storage battery charging panel. Figure 61 shows the front of this charging panel.

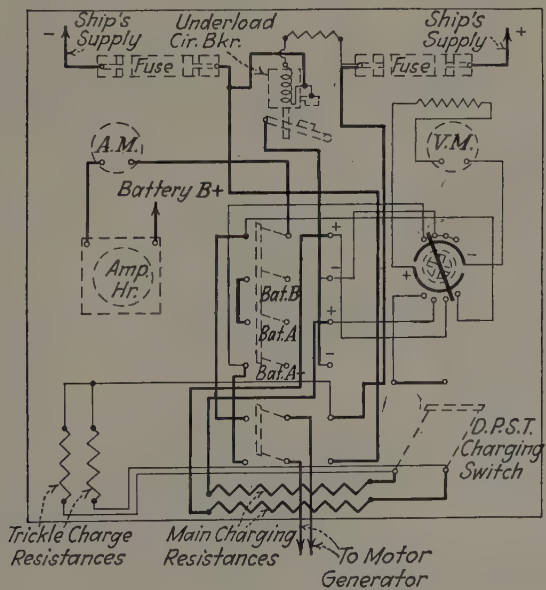


FIG. 60.—Navy standard charging panel (complete).

On the front of the board are located various instruments, *i.e.*, voltmeter, ammeter, wattmeter, circuit breaker, selector switch for voltmeter, switch for placing batteries on charge and discharge, switch for changing radio motor generator source of power from ship's generator to batteries, trickle-charge switch, and two main line fuses.

Before the purpose of these instruments and switches is understood, it will be necessary to study very carefully the charging diagram.

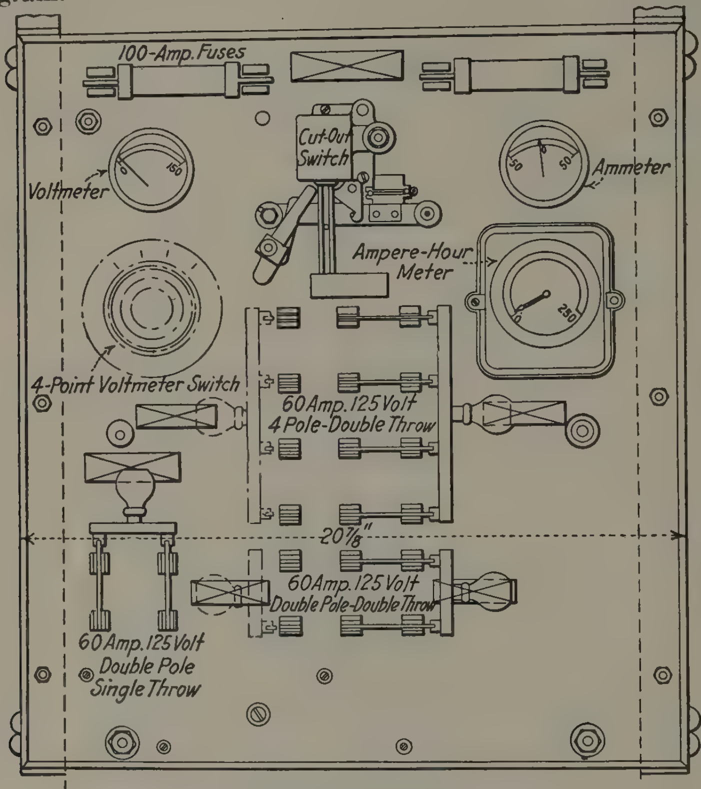


FIG. 61.—Navy standard charging panel.

The voltmeter is arranged with a four-point selector switch so readings may be taken as follows:

Point 1 gives the voltage of ship's line.
Point 2 gives reading of *B* group of storage batteries.
Point 3 gives reading of *A* group of storage batteries.
Point 4 gives total voltage of batteries on discharge.

It is important that the ship's voltage be known, because the charging voltage must be of a definite value.

The ammeter reads either charge or discharge current, depending upon which way the large four-pole switch is thrown. It is a zero-center meter: in other words, the zero mark is in the center of the scale. The meter reads toward one side for charge and toward the other side for discharge.

The Sangamo ampere-hour meter is of the mercury-motor type and gives the exact state of charge of the battery equipment. It reads ampere hours directly on a scale. The scale also has a minimum pointer which is painted red and may be fixed at any

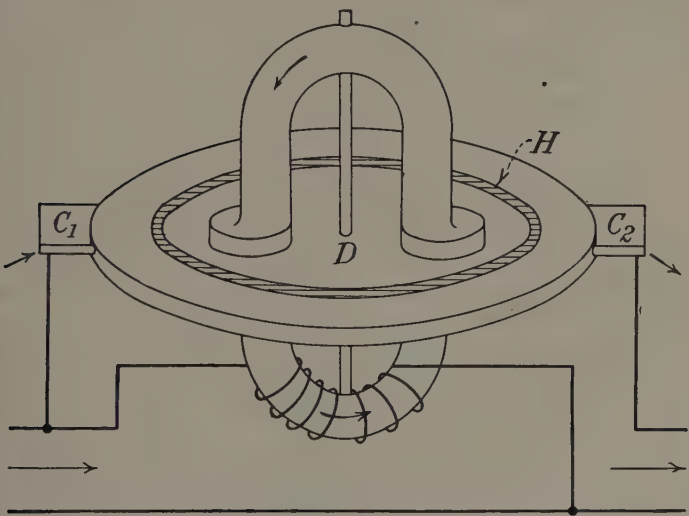


FIG. 62.—Principle of Sangamo watt-hour meter. (See Fig. 65*a*.)

definite point. When the charge drops to this point the batteries should be placed on charge immediately.

The mercury motor of the watt-hour meter is coupled to a revolution-recording mechanism and its speed is proportional to the power flowing through it.

The mercury motor consists essentially of a copper disc floating in mercury between the poles of a magnet and provided with leads to and from the mercury at diametrically opposite points. The theoretical relations of the various parts are shown in Fig. 62. The current of electricity, carried by the circuit in which the energy is to be measured, enters the contact C^1, passes through the comparatively high-resistance mercury H, to the edge of the

low-resistance copper disc D, across through the disc to the mercury H, and out of contact C^2.

The magnetic field of the motor is excited by a winding connected across the circuit, in which energy is to be measured.

The relative directions of the magnetic flux and the current of electricity, as well as the resulting motion, are shown in Fig. 63.

When connected to the line the Sangamo meter requires a driving force directly proportional to its speed of rotation, the mercury motor then becomes a meter. The speed of such a meter is a measure of the power, or rate of flow of the energy, through the motor element, and each revolution of the motor corresponds to a given quantity of energy.

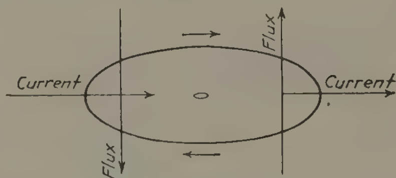


Fig. 63.—Results of current flow in watt-hour meter.

By connecting a revolution counter to this motor a means of recording in watt-hours the total quantity of energy that has passed is provided.

There is a third connection on the ampere-hour meter to the overload or underload circuit breaker, which automatically opens the charging circuit should there be either an overload or an underload voltage on the charging main. This prevents damage to the batteries.

Circuit Breakers.—The circuit breaker used to protect the storage battery from discharging back through the generator, if the charging voltage falls below a certain value, is called an "underload" circuit breaker. This type is illustrated in Fig. 61 and is also called a "cutout switch." When the switch is closed and current is flowing in the line, the magnet coil is energized and through a latch arrangement prevents the switch blade from flying open. A spring tends to open the switch, and does so when the current is shut off or falls so low that the solenoid in the magnet coil drops, releasing the latch. If there is no voltage on the line, the switch handle will not stay closed, as the lacth

will not operate. The magnet coil is connected, one end directly to the line, the other end through a contact switch which is closed only when the breaker is thrown in. The four-pole, double-throw switch in the center serves to place the batteries on charge and discharge. The theoretical function of the underload circuit breaker is extremely simple and can readily be understood by referring to Fig. 60 at the point marked "Underload Cir. Bkr." Briefly, when a current passes through the coil of this release magnet it is magnetized and holds up the plunger, thus completing the contact from the plus side of the line to the charging resistance. This coil is wound with the proper number of turns to hold the plunger during the period that the battery is on charge at the usual charging voltage 110 to 120 volts. If the charging voltage of the ship's generator falls below normal, however, the current passing through the solenoid coil decreases and, therefore, loses some of its magnetic strength, which results in a release of the plunger and the breaking of the circuit at the point marked "contact." Thus, if the ship's voltage should ever drop below the voltage of the batteries by this arrangement of the circuit breaker the batteries will be prevented from discharging back through the ship's generator.

The Overload Circuit Breaker.—In power circuits where the apparatus is to be protected from overload, fuses and overload circuit breakers must be used. On all panels in commercial equipment the overload circuit breaker is usually connected in the motor armature and generator circuits. For example, if the plunger in the automatic starter (Fig. 35) should rise too quickly the starting box resistances would be rapidly cut out and a heavy current flow would result through the armature windings. If this were not amply protected by fuses and circuit breakers, the armature winding, due to its low resistance, would be subjected to heavy currents and the result might be a burning out of one or more of the armature coils. The overload circuit breaker in Fig. 64 is illustrated as being connected in series with the armature circuit to protect against excessive current flow through the armature winding.

When the handle of the overload breaker is pressed down, a copper, laminated spring is pressed against contacts C_1 and C_2. This allows the current to flow through the armature and the over-

load magnet at A. It is quite obvious that as soon as a current flows through A the overload magnet is magnetized. The degree of magnetization depends upon the amount of current flowing through the armature. This magnet will attract the iron bar M upwards toward the magnet at point X. This results in point Y dropping, which causes the release of the latch at point L.

Point L then takes the position of the dotted line L_1, which causes a release of the handle from points R to S, incidentally releasing the copper spring A from contacts C_1 and C_2, causing a break in the armature circuit.

The circuit breaker must be carefully adjusted so that it will not *trip* when the proper amount of current is flowing through

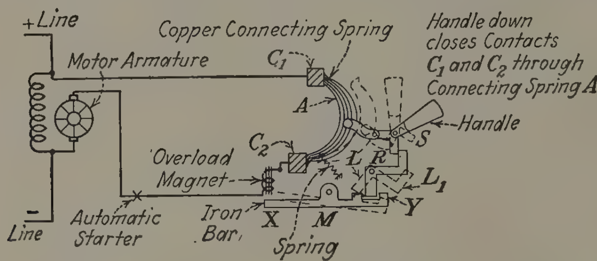


FIG. 64.—Electrical and mechanical arrangement overload circuit breaker.

the armature. This is accomplished by lowering the iron bar so that the distance between the bar and the magnet is increased to the proper distance. For example, if a motor, on starting, has been designed to safely draw 10 amp. then the iron bar must be moved far enough away from the overload magnet so that it will not break the circuit at that particular current flow. This is usually determined by experiment, although in many cases the amount of space for various amperages is marked above the adjusting screw.

The double-pole, single-throw switch in the lower left-hand corner of the panel serves to place the cells on trickle or floating charge. This allows a current of small value to flow continually through the cells, while discharge is not taking place, thereby preventing an internal discharge from taking place.

Resistances for the charging circuit are made up in units such as the one shown in Fig. 65. These are mounted on the rear of the panel.

Operating the Switchboard.—The following explanation has to do with Fig. 66.

Checking Polarity.—First determine that the power-bus switch is closed in the proper direction by observing whether the voltmeter reads when the plug switch is in the left-hand receptacle. If it does not read, reverse the power-bus switch, then ascertain that the two halves of the battery are also properly connected by taking readings in the upper and lower right-hand receptacles.

The voltmeter circuit is normally open and a push-button switch is provided on the switchboard for closing the circuit when

FIG. 65.—Charging resistance unit.

FIG. 65*a*.—Sangamo ampere-hour meter.

it is desired to take a voltage reading. This precaution is taken to prevent inductive effects incidental to the operation of the radio outfit, from damaging the meter.

Charging Battery.—Open the 6-PDT switch. Close the circuit breaker, at the same time holding up the plunger of the low-voltage release coil, then close the 6-PDT switch to the left. This will place the respective halves of the battery on charge through the charging resistance on the back of the board which should become uniformly warm. The red pointer on the ampere-hour meter should be set at the ampere-hour capacity of the batteries. The

black hand of the ampere-hour meter indicates the state of discharge of the battery at any time. As soon as the charge is started, the black hand will begin to move towards zero and the charge should be complete when it reaches zero. When the black hand reaches zero it makes a contact which opens the circuit breaker by means of the automatic trip, thus automatically cutting off the charge. For the semimonthly charge, or if for some other reason the battery requires an overcharge, it is necessary to remove the cover from the ampere-hour meter and turn the black hand to about 50.

If the ship's power circuit fails while the battery is charging, the low-voltage release will open the circuit breaker, preventing the battery from discharging back into the ship's line. The battery can be used for supplying current in such an emergency as described under Discharging the Battery.

Floating Battery.—With the 6-PDT switch closed to the left and the circuit breaker open, the charging circuit through the resistance units will be open, but the battery will be receiving a floating charge through the two lamps mounted in the upper corners of the switchboard. This is intended to be the normal condition of operation; *i.e.*, battery fully charged and floating with circuit breaker open and 6-P switch closed to the left. With the 6-P switch in this position the radio circuit is connected directly to the ship's line.

Note.—The abbreviation "6-PDT" means six-pole, double-throw switch. A double-pole, double-throw switch would be designated "DPDT," likewise, a single-pole, single-throw switch is called "SPST."

The *floating charge*, or *trickle charge*, as it is called, is necessary in emergency equipments where the batteries are seldom used and where a small but steady discharge is, nevertheless, taking place. The question now naturally comes to mind as to the character of this small but steady discharge. Because of impurities in the active material, impurities in the electrolyte, leaks in the wiring, and such other causes, there is a constant tendency for cells to discharge. The pent-up energy within them is striving to get out, and there is a small discharge. To stop this discharge, a charging current of equal strength to this discharging current must be sent into the battery. It is of very small value and is called the

"floating" or "trickle" charge. It is just enough to compensate for the local action, therefore, the battery does not run down. Furthermore, the battery is not overcharged by this small charging current because it is of such small value that it does not charge the battery but merely prevents it from discharging.

When the battery is floating or charging, then the lights in the radio room must be operated from the ship's power lines, and the lower double-pole, double-throw switch should be closed to the left. The feeder switches for the various light circuits can be opened or closed as desired.

Discharging Battery.—With the circuit breaker open, close the 6-P switch to the right.

With the battery discharging, the lights may be operated from either the bus of the battery by closing the small lower double-pole, double-throw switch to the left or right, respectively.

Ship's Power Off.—Whenever the ship's dynamo is shut down, care should be taken to open the radio-circuit switch on the ship's switchboard, and all switches on the battery switchboard. Do not burn lights from the battery at such times except for emergency.

OPERATING THE BATTERY

("Exide" or "Ironclad-Exide" Battery)

Replacing Evaporation.—Keep the electrolyte always above the top of the plates by adding pure, fresh water (never anything else) to a height ½ in. (not more) above top of plates. The best time for adding water is just before a charge. Do not add water while charging or immediately after. Do not use metallic receptacles for holding the water.

Caution.—Keep flames of all kinds (match, candle, lantern, cigar, etc.) away from battery at all times. Keep all filling plugs in place, except when necessary to remove them for adding water, reading specific gravity, or observing gassing.

Floating Trickle Charge.—Battery is to be *floated* at all times. When floating, both lamps on the battery switchboard will burn dimly. If either lamp goes out, immediately replace it with another of the same rating.

Charging.—Twice each month, preferably when in port, charge the battery (see Switchboard Instruction). Move the

black hand to the ampere-hour meter back to about 50 and charge until the *pilot cell gravity* and the voltage of each side have remained constant for 1 hr. and all cells have been gassing or bubbling freely for the same length of time. This means that under normal floating conditions the charge will be of about 1¼ hr. duration. The *pilot cell gravity* is a reading with the

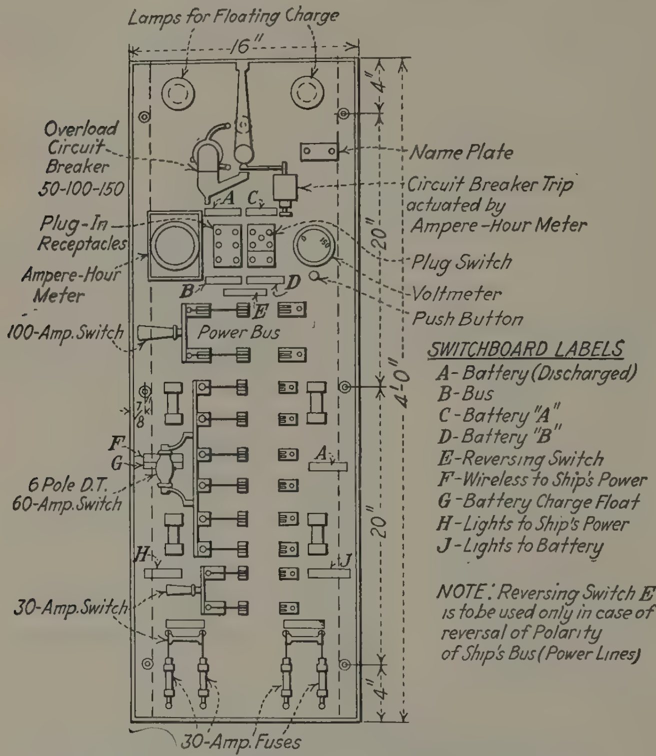


FIG. 66.—Front of switchboard (emergency equipment). (*Electric Storage Battery Co.*)

hydrometer syringe, taken in one marked cell in each half of the battery, representing the rest of the cells. Raise the covers of the battery box during this charge. After the charge, reset the black hand of the ampere-hour meter to zero.

After a discharge of any kind, immediately put the battery on charge and continue the charging until the black hand of the ampere-hour meter has returned to zero.

Generator Polarity.—In order to check the generator polarity and to guard against the battery becoming accidentally discharged through the reversal of the generator, read the voltmeter frequently with the voltmeter plug in openings marked "bus." If the polarity has changed, throw over the switch marked "reversing switch."

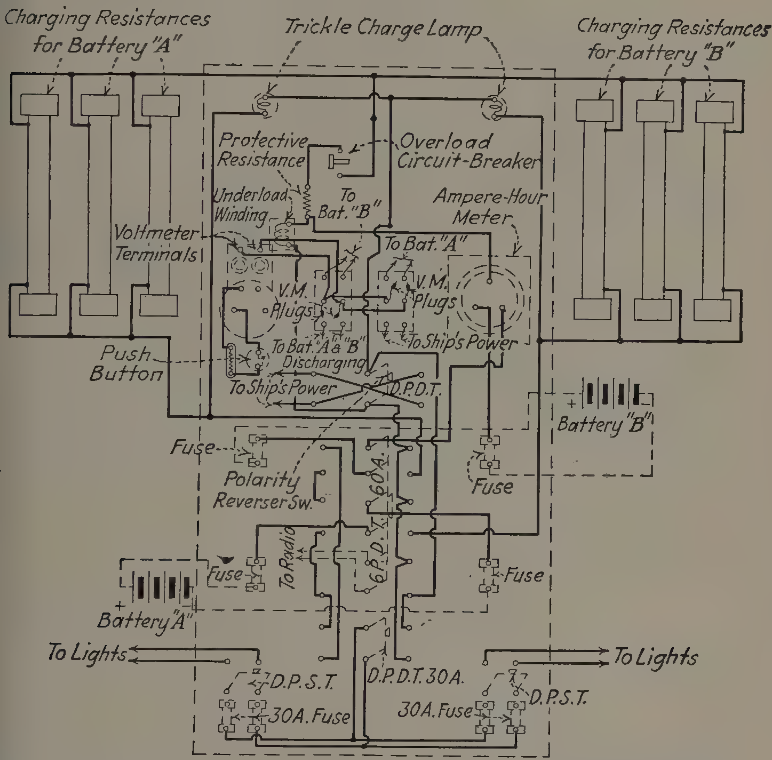


Fig. 67.—Electric storage-battery charging panel (rear-view wiring diagram).

Readings.—Before the semimonthly charge and before adding water to the cells, read and record the specific gravity of each cell of the battery. Immediately after the semimonthly charge, read and record the specific gravity of the pilot cells. On other days, read and record the specific gravity of the pilot cells at the same time each day. These readings will indicate the state of charge of battery and will be a check on the *floating*.

Inspection.—If the gravity of any cell shows a marked falling off relative to the rest of the cells, promptly investigate the cause and correct it. If a cell becomes dead from a leaky jar, cut it out of the circuit by opening up the connector and restore the circuit with a jumper. If a jar develops a leak, promptly replace it.

Bus Voltage.—When charging keep the bus voltage at 110 volts, as, if it is low, the charging rate will be reduced and the time required to charge correspondingly increased.

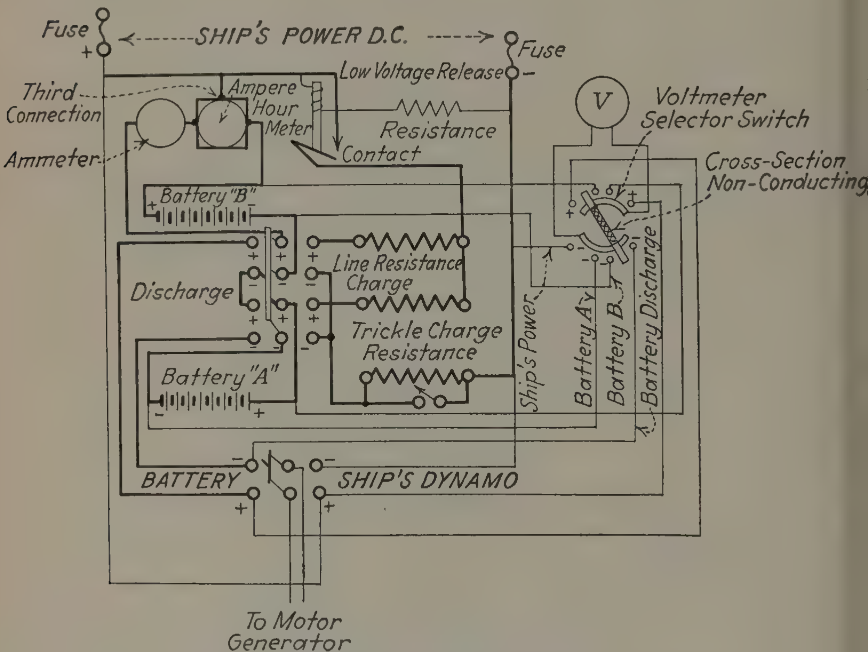


FIG. 68.—Schematic wiring diagram, Navy standard charging panel.

Cleanliness.—Keep everything about the battery clean and dry. Keep connections tight and free from corrosion. Do not allow any impurities to get into a cell.

The two fuses of 100-amp. capacity each protect the ship's line and generator against any damage which a short-circuit of any kind would produce.

Emergency Charging.—If the charging resistances on any of the standard charging panels become inoperative a simple sub-

stitute can be made which will satisfactorily charge the entire battery installation.

This arrangement includes a number of lamp sockets mounted on a baseboard and connected in parallel. This parallel bank can then be connected in place of the burned out resistance unit and the current flow regulated by cutting in or out a number of lamps.

For example, if one 75 watt lamp is connected in place of the resistance unit in Fig. 46 approximately ½ ampere will flow into the battery.

Thus, if two 75 watt lamps are connected in parallel then 1 ampere would flow into the battery. Hence, if one of the standard charging resistances burned out a considerable number of lamps could be connected in parallel until the desired current flow is obtained.

Questions

1. Explain the electrical function of the overload circuit breaker.
2. Where are circuit breakers usually connected?
3. What is the difference between the overload and the underload circuit breaker?
4. Draw a diagram of a standard charging panel.
5. Describe the practical operation of the panel when charging batteries.

CHAPTER X

THE INDUCTION COIL AND TRANSFORMER

The Induction Coil.—The induction coil is a device for raising a low-potential direct current to a high-potential alternating current. The induction coil consists of a soft iron core, a pri-

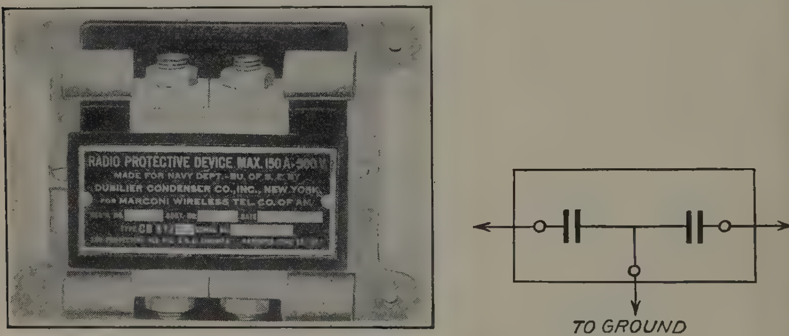


FIG. 69.—Protective condenser.

mary winding and a secondary winding. These are shown in the Fig. 70*b*. The primary of the coil is connected to a source of direct current, usually of a low voltage. The theoretical function may be described as follows: As soon as the key *K* is closed, the current flows through the primary winding, which

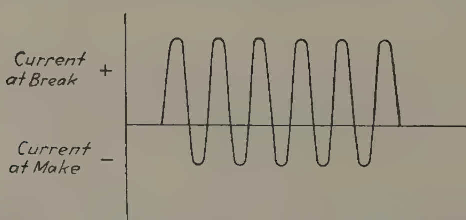


FIG. 70*a*.—Alternating-current wave form, induction coil.

consists of a relatively few turns of heavy wire. In the diagram the primary is indicated by the dark, heavy turns

and the secondary by the lighter turns. An important part of the induction coil is the vibrator fixed to one end of the coil and indicated by the letters *MVP*. The piece *M* is a vibrating piece of spring steel with a platinum or silver contact point

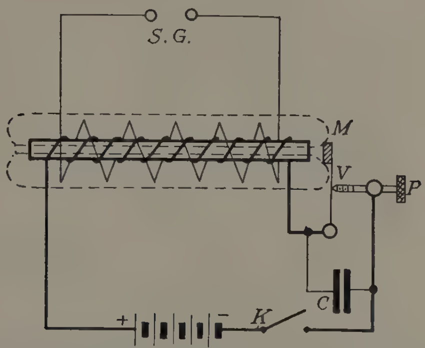


FIG. 70*b*.—Wiring diagram of an induction coil.

where it makes contact with the adjusting screw *P*. This point is designated by the letter *V*. Now, as was explained before, when the key is closed, the current commences to flow through the primary circuit. Before the current starts to flow, the contact of the vibrator *V* is closed as the spring action of the arm *M* keeps it in this position. As soon as the current flows through the primary winding, it makes a magnet of the iron core *I*, which immediately draws the vibrator arm *M* towards it, breaking the contact at *V* and opening the primary circuit. As soon as the circuit is broken, the current stops flowing through the primary winding and the iron core loses its magnetism. The magnetism of the core was what drew the arm *M* towards it, and now that this magnetism has been lost this arm flies back to its natural position which again establishes contact at *V* and the circuit is completed.

One cycle of vibration of the vibrator has been observed. This operation takes but a fraction of a second and as soon as the vibrating arm remakes the contact the operation is repeated, giving a sound to the vibrator not unlike an ordinary buzzer. So far as induction is concerned, the current flows through the primary winding but for a fraction of a second. As soon as it starts to flow, the whole winding is surrounded by a magnetic

field of force which cuts the secondary winding. When the secondary winding is cut there is induced in it an e.m.f. This secondary current is low in current value (amperes) but high in voltage or potential value. The primary current flows in intermittent pulses, slowly building up from zero value to maximum at which instant the contact breaks and the current value falls to zero. This fall in the value of the current is much quicker than its rise. In fact, the rise is so slow in relation to the fall that the current induced during the rise can be neglected and it may be assumed that all the current is induced in the secondary during the fall or breakdown of the primary current. It should be noted that although the interrupted direct current in the primary induces an alternating current in the secondary, the induced e.m.f. in the secondary is considerably more at the *break* of the primary current than at the *make*. This is due to the more rapid change of the lines of force in cutting the winding S when collapsing. It is a direct result of the saturation characteristic of the iron core. In other words, the iron offers a greater opposition to the expanding field due to the molecular friction produced in it and, therefore, tends to oppose the magnetizing effect of the current. Thus, when the field collapses at *break*, the molecules readily fall back into their original distorted position and offer no opposition to the current flow in the circuit, but, on the contrary, tend to aid it (see Fig. 70a for illustration of the wave motion produced by an induction coil). The current in the secondary rises and falls with the current of the primary. If the vibrator of the coil makes and breaks the circuit sixty times per second then the primary and the secondary currents rise and fall just that many times per second.

The contact points of the vibrator are protected against damage due to excessive sparking by the condenser C, which may be from ¼ to 1-mf. capacity depending upon the size of the coil. Condensers will be discussed in the next chapter.

The secondary discharges across the spark gap S.G. When the coil is used for transmitting purposes, however, a condenser is connected across the spark gap to make up the oscillating circuit which will be explained in a subsequent chapter.

The secondary winding of an induction coil which is wound directly over the primary winding is wound, unless the coil is but

a very small one, in the form of sections or pies, so that if by any chance several turns are punctured they may be repaired without rewinding the whole secondary. The secondary is also heavily insulated from the primary winding by a hard rubber or mica insulation.

The induction coil is an open-core transformer fitted with a mechanical vibrator or interrupter. The disadvantage of the induction coil is that its power is limited to the capacity of the interrupter.

The Alternating-current Transformer.—Transformers are divided into two classes: step-down and step-up. The ratio of transformation depends entirely upon the ratio of the primary turns to the secondary turns. If the primary has 100 turns and the secondary 10 turns, the ratio is 10 to 1. The voltage at the secondary terminals will, therefore, be stepped-down in the same ratio. Suppose that 1,000 volts are impressed on the primary; then one-tenth of this value will come out of the secondary, that is, 100 volts. If the values are reversed and the primary has 100 turns and the secondary 1,000 turns, the ratio will be 1 to 10, instead of 10 to 1. If the voltage impressed across the primary is in this case 100 volts the secondary will step it up to ten times this value or 1,000 volts. This ratio of transformation does not hold absolutely in practice, but as the transformer is one of the most efficient pieces of electrical machinery—in some cases 98 per cent efficient—this ratio can be used for all ordinary purposes.

By the application of various formulas comparative voltages, currents and turn ratios between primary and secondaries may be computed.

Some of the more important formulas are listed below:

$$\text{Turn ratio} = \frac{Nhv}{Nlv}.$$

$$\text{Voltage ratio} = \frac{Ep}{Es}.$$

$$\text{Current ratio} = \frac{Ip}{Is}.$$

where

$$N = \text{number of turns.}$$
$$hv = \text{high voltage.}$$
$$lv = \text{low voltage.}$$
$$E_p = \text{primary voltage.}$$
$$E_S = \text{secondary voltage.}$$
$$I_p = \text{primary current.}$$
$$I_S = \text{secondary current.}$$

Similarly, the power, current, voltage and power-factor relations in the transformer primary and secondary windings may be derived from the fact that the power input to any device must be always equal to its output, plus the power losses. In as much as the modern form of efficient transformer has very small losses, the primary and secondary powers are very nearly equal. This is expressed by the formula

$$Pp = Ps \text{ (watts).}$$

where

$$Pp = \text{primary power.}$$
$$Ps = \text{secondary power.}$$

Therefore the complete formula for voltage, current and the power factor for both primary and secondary circuits would be expressed as follows:

$$Ep \times Ip \times \text{p.f.}p. = Es \times Is \times \text{p.f.}$$
$$Pp = Es \times Is \times \text{p.f.}s.$$
$$Ps = Ep \times Ip \times \text{p.f.}p.$$

where,

Is = current in the secondary expressed in amperes.
Ip = current in the primary expressed in amperes.
Pp = the power input to the primary expressed in watts.
Ps = the power output of the secondary expressed in watts.
p.f.p. = power factor in primary.
p.f.s. = power factor in secondary.

Hence,

$$Ep \times Ip = Es \times Is$$

Thus, for practical working purposes the formulas are written as follows:

$$Ep = \frac{Es \times Is}{Ip} \text{ (volts).}$$

$$Ip = \frac{Es \times Is}{Ep} \text{ (amperes).}$$

$$Es = \frac{Ep \times Ip}{Is} \text{ (volts).}$$

$$Is = \frac{Ep \times Ip}{Es} \text{ (amperes).}$$

Function and Operation of the Transformer.—The function of the transformer is either to step-up or step-down the voltage introduced into its primary winding. It does this through an induction process between the windings. In radio work, step-up transformers are almost entirely used, and the step-down type will be discussed no farther. In a radio transmitter it is the purpose of the transformer to step-up the voltage to a potential so high that the condensers in the oscillating circuit will be charged and in turn discharge through the spark gap. This causes the high-frequency oscillations necessary to the propagation of ether waves.

The alternating current flowing from the armature of the generator flows through the primary winding of the transformer. This causes a rising and falling magnetic field to cut the secondary winding at the rate of the current frequency. For example, if a 500-cycle generator is employed, these lines of force will rise and fall 500 times per second, cutting the secondary winding twice for each cycle, one as it is rising and one as it is falling, thus cutting the secondary making 1,000 times per second. The fundamental principle is this. Whenever a conductor is cut by lines of force, a current is induced therein. Consequently, there is induced in the secondary an alternating current of the same frequency, but of a much higher voltage than that of the primary circuit. Remember the transformer does not effect the frequency, although it does affect other characteristics of the impressed current.

The transformer, like all other electrical machinery, has certain losses. These are known as core losses and copper losses.

In well-designed transformers, these losses are reduced to a minimum and give no great concern unless the transformer is

overloaded. Core losses include hysteresis losses, caused by small molecular action, which will be explained later.

Transformers are usually designed to work with a certain generator, both being designed for the same frequency. The circuit, consisting of the secondary of the transformer, condensers, spark gap, etc., is so designed that the current flowing in this circuit is in phase with the current flowing in the armature and primary circuit. A coil known as a "reactance coil" is sometimes used in series with the primary current to regulate the current flowing through it. A reactance coil consists of an iron core over which is wound a few turns of heavy, insulated copper wire, taps being taken off and lead to a multi-point switch as shown in the diagram (Fig. 71*a*).

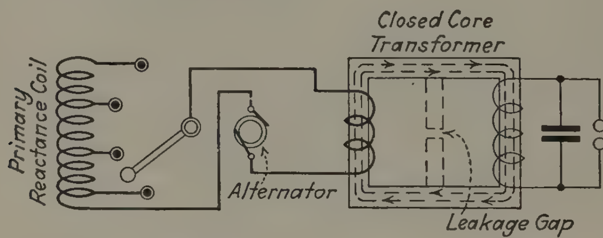


FIG. 71*a*.—Reactance coil in a transformer circuit.

The standard transformer is designed to give from 10,000 to 30,000 volts in the secondary using 500 cycle, 120 volts in the primary.

Kinds of Transformers.—The transformer is made in two forms for radio use; namely, open core and closed core. This classification comes from the way in which the magnetic field is completed.

In Fig. 70*b* the induction coil illustrated is an open-core transformer, and the magnetic lines of force complete their path, after leaving the iron core, through the air. The path is indicated by dotted lines in the figure. The core of the closed-core transformer provides a complete magnetic field through iron, as indicated by dotted lines in Fig. 71*a*. It is from this fact that it takes its name, "closed core."

Open-core Transformer.—This type of transformer has all the mechanical features of the induction coil except the interrupter.

The step-up types used for radio are almost always of much larger dimensions than is the induction coil. It will be remembered that the induction coil is limited in its size by the amount of current the interrupter is able to handle; the transformer has no such limiting parts. As was mentioned before, the magnetic field of the open core transformer is completed through the air. It has a core which is usually made up of strips of thin sheet soft iron. Each lamination being insulated one from the other by japanning or shellacking to reduce losses, as previously explained. The other parts are constructed much in the same way as explained under the induction coil.

This type is often referred to as a "constant-current" transformer. This is because it draws practically the same current when the secondary is on short-circuit as when it is open. Owing to the open magnetic field path, there is little magnetic reaction of the secondary upon the primary, with the result that the primary current remains nearly constant. The closed-core transformer, to be explained next, provides for this regulation through a magnetic leakage gap, shown by dotted lines in Fig. 71*a*.

Closed-core Transformer.—This type of transformer is the one most commonly used in radio equipment today. Figure 71*a* shows the construction in detail and also the method of connection to the generator and oscillating circuits. In this case, the magnetic circuit is completed entirely through the iron core as indicated by the dotted lines. Notice that the primary and the secondary are not wound one over the other as in the open-core type but on each side of two sides of the soft-iron core. The primary winding in this type, as in the case of all step-up transformers, consists of heavy wire such as No. 10 or 12 B. & S. gage, and the secondary may have several thousand turns of fine wire such as No. 30 or 32 B. & S. gage. The leakage gap, shown in the diagram by dotted lines, serves to compensate for any reaction between the primary and the secondary and thereby keeps constant the current drawn by the primary.

In the modern types of transformers the secondary winding is placed in sections, called "pies" as in Fig. 71*b*.

This arrangement tends to distribute the voltage strain and also makes the repair of individual sections more practical.

Another protective arrangement on transformers is a small gap connected directly across the secondary terminals. This is known as a safety gap and tends to prevent damage to the windings in case of strain.

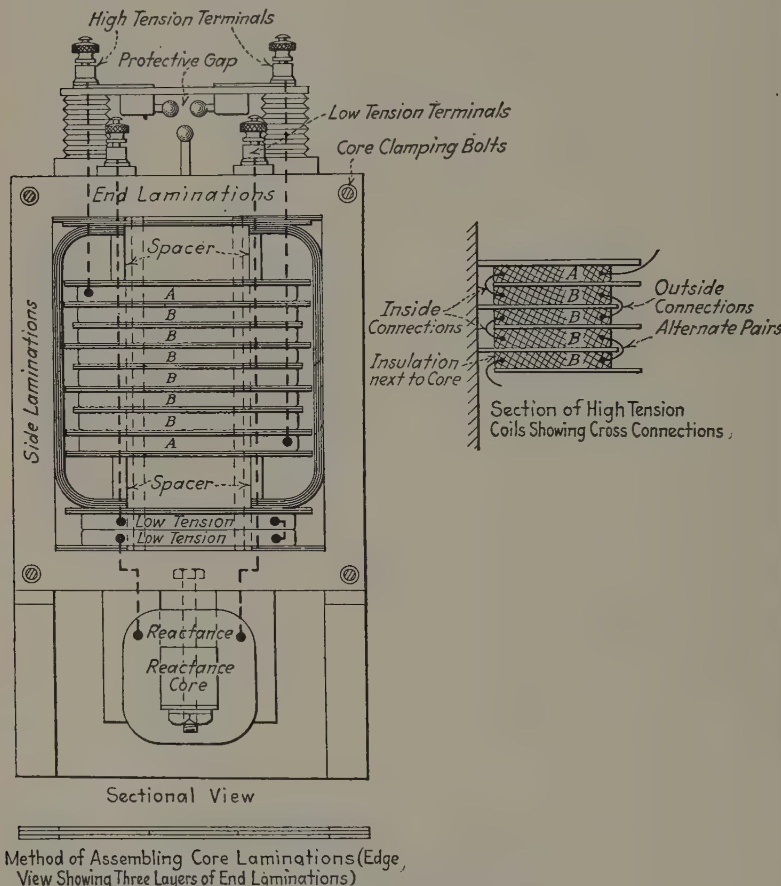


FIG. 71b.—Assembly and connections of a standard transformer.

Transformer Losses.—The principal losses associated with transformers are iron and heat losses due to hysteresis and eddy currents.

Hysteresis is known as that phenomena whereby energy is dissipated in the form of heat due to the magnetic reversals

caused by the current through the windings, resulting in molecular friction in the iron. This is minimized by the use of a special type of magnetic material having an extremely small tendency towards molecular friction. This material is known as *silicon steel.* Other alloys recently compounded have been found to possess a higher permeability than silicon steel. These are known by various trade names such as *Ajax metal* and *Permalloy.*

Other serious heat producers are the small eddy currents set up in the steel. These small currents are set up in the form of whorls and tend to oppose the magnetizing force to such an extent that considerable losses will result. These small currents may be broken up by breaking up the core into sheets instead making it of a solid mass. This is called "laminating" the steel.

After all of these losses have been carefully minimized the efficiency of the transformer may reach 98 per cent.

Questions

1. What is the theoretical operation of the induction coil?
2. Describe the construction of a power transformer.
3. What is the difference between the induction coil and the transformer?
4. What are transformers used for?
5. What are the principal losses in transformers?
6. How are these losses minimized?
7. What is meant by the turn ratio of a transformer winding?
8. Draw a diagram of a closed-core transformer.
9. How are transformer breakdowns prevented?
10. What is the difference between a step-up and a step-down transformer?

CHAPTER XI

ELECTROSTATIC CAPACITY

In order that the student may obtain a clear understanding of radio circuits, in which the most dominant factors are capacity and inductance, the following explanation relative to the theory of condenser action must be carefully digested.

Dielectrics.—Certain substances will not conduct an electric current, that is, when a difference of potential or pressure is applied there is no movement of electrons and, hence, no flow of current. Materials of this kind are called "dielectrics" or "insulators." This effect is probably due to the atomic structure

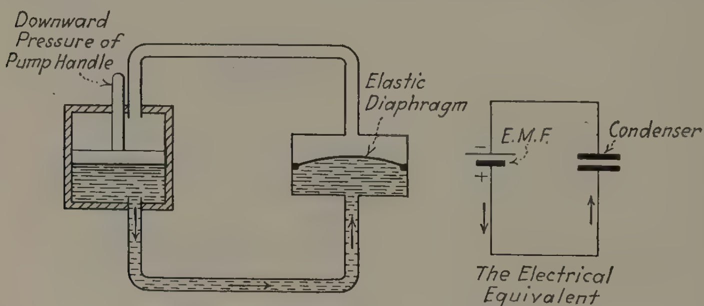


FIG. 72.—Water analogy for a condenser.

of the substance whereby the electrons, when subjected to a difference of potential, will not leave their respective atoms and therefore will not constitute a flow of electric current. An electric current is a movement of electrons from atom to atom. If the electric force is capable of extending the electron of the dielectric from its atom, however, the dielectric will be defined as being in a strained position. For example, Fig. 72 shows a small water tank fitted with an elastic plate. Here the elastic will be strained when the water pressure is turned on. A dielectric substance will act in a similar manner as long as the electrical

pressure remains constant. If the water pressure in Fig. 72 is increased to a great extent, there is a possibility of rupturing the elastic and, in a like manner, an electrical dielectric might be strained to a point of rupture. In either example, as soon as a rupture occurs, a current will flow and the material will no longer be termed an insulator but a conductor. Thus, a ruptured insulator might be defined as a material in which the electrons have been extended beyond their limit, or, in other words, the electrons have been strained beyond the elastic limit of the atomic structure and the insulating material now becomes a conductor.

The Condenser.—The theoretical function of the condenser is based almost entirely on this insulating property of certain

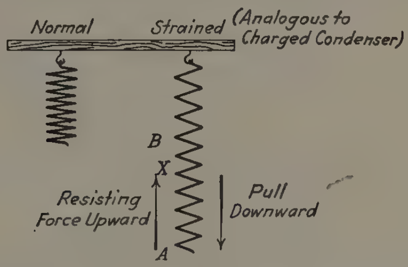


FIG. 73*a*.—Spring analogy for a charged condenser.

materials. The material must not rupture, it must be capable of holding under a strain so that the energy which has been stored up in the dielectric can be used for the production of currents at high frequencies. How this is accomplished will be seen after a simple mechanical analogy has been given.

Figure 73*a* illustrates the mechanical application to the condenser theory.

While the spring is at rest, no force will be exerted by it. As soon as the spring is strained by pulling it downward, however, it will obviously tend to resist or oppose the pulling effect in the opposite direction, the amount of opposition being dependent upon the springiness or flexibility of the spring.

In a like manner will a condenser, owing to the straining of the dielectric by the applied potential, have forced into it an electrical strain. As soon as the dielectric is strained it will exert a force

in the opposite direction. Furthermore, the quantity of electricity which has passed into the condenser for a given applied force depends upon the capacity of the condenser.

If the flexibility of the spring is due to its length and diameter, thinness of its material, and its mechanical elasticity, similarly does the capacity of the condenser depend upon three factors, namely "the area of the metallic plates on each side of the dielectric," "the thinness of the dielectric" and "the inductive capacity of the dielectric."

It is important that the student understands the term "inductive capacity of the dielectric" as the straining action of the dielectric, and that the reason for the condenser holding electricity is due only to this property. That is, just as the spring has the property of holding a strain due to its springiness, and not due to the applied force, so will the condenser store up energy due to its "inductive capacity."

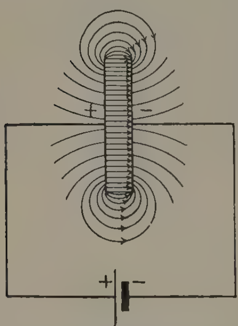


FIG. 73*b*.—Electrostatic field in a condenser.

Electric Theory of a Condenser Charge.—Assume two plates of a condenser connected to a source of potential as in Fig. 73*b*. If one metal plate is connected to the positive terminal and the other to the negative terminal and the two plates brought close together, a field of electric force will be produced in the dielectric between them, and a displacement of electrons will result in the direction of the positive plate. In conventional terms, however, when the electrical displacement is mentioned it is said that the displacement is from the positive to the negative plate.

During the time that this displacement is taking place in the atomic structure of the dielectric, there will be a movement of electrons in the external circuit from the negative plate to the positive plate. The accumulations or charges on both these plates therefore, will be increased, *i.e.*, the negative plate will acquire a greater negative charge and the positive plate a greater positive charge. The summation of charges on each plate is balanced and is therefore always zero. When these charges are referred to it simply means a quantity of electricity on one of the

plates, either the positive or the negative plate. The charge on the positive plate is the one generally referred to.

The Dielectric Current.—In the ordinary battery circuit a constant current will flow when the circuit is closed and the pressure kept constant. In the condenser, however, the current flow is only momentary, when the two plates are connected to a battery. For example, if a simple condenser, as in Fig. 74, is connected with a sensitive galvanometer, there will be recorded a sudden deflection when the switch is closed which gradually drops to zero. This momentary current flow is due to the *springiness* of the dielectric produced the moment the switch was closed and lasts only for a brief period because the strain is now kept constant.

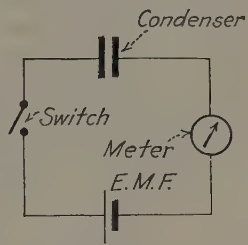


FIG. 74.—Meter connection for showing displacement current.

When the pressure is allowed to diminish, the elasticity or springiness of the dielectric material again produces a current flow in the opposite direction, replacing the current, so to speak, and hence the flow of current in a condenser, when the strain or displacement is changing, is called a "displacement current" or a "dielectric current."

Confusion sometimes arises over the belief that the displacement current is actually a movement of charges from one plate to the other within the substance. This is not true. It is simply a straining effect caused by the positive charges in each molecule of the dielectric being moved to one end and the negative charges of the molecule moved to the other end at the instant the switch is closed. During the period that the electrons are pushed outward from their respective atoms of the dielectric material they constitute a flow. This flow of current immediately ceases, as soon as the electrons have moved their full distance. Thus, the internal action of a condenser may be defined as a movement of charges across the dielectric, in the form of positive and negative charges, the positive charges pointing in one direction and the negative charges in the other direction.

When a dielectric is in this strained condition, it possesses a potential in an "electrostatic" form, or, in other words, an electrical charge.

It can thus be seen that a charge may be placed in a condenser whenever it is connected to an e.m.f., and that a current can be made to flow in the condenser whenever the e.m.f. changes. In a direct-current circuit of constant potential, therefore, the condenser will be charged almost as soon as it is connected but the flow of displacement current will only be momentary. If the condenser is placed across an alternating e.m.f., however, a displacement current will flow due to the reversals of the applied e.m.f. and, therefore, the electric strain in the condenser reverses its direction with every reversal of the applied e.m.f. Thus the existence of the electric strain or displacement in the dielectric is equivalent to the presence of a quantity or charge of electricity.

The quantity of charge is expressed as Q and is found to be directly proportional to the applied voltage E.

$$\text{Thus } Q = C \times E \quad \text{or} \quad Q = CE.$$

Here C is termed a constant and is seen to be the ratio of the charge to the voltage, or

$$C = \frac{Q}{E}.$$

This constant is called the "capacity" of the condenser and is usually referred to by units; *i.e.*, "microfarad" or "micro-microfarad." The actual unit is called the "farad" but due to its enormous capacity is not used and therefore the microfarad and the micro-microfarad are the fractional units used in radio.

The microfarad is $\frac{1}{1,000,000}$ part of a farad and the micro-microfarad is $\frac{1}{1,000,000}$ part of a microfarad.

For example, if a condenser has a capacity of 0.001 mf., the value in micro-microfarads would be 1,000 mmf. Similarly if the capacity is expressed in micro-microfarads it can readily be converted into microfarads.

The Dielectric Constant.—The charge accumulated on the plates of the condenser, for a given voltage and space between the plates, depends upon the dielectric material. Assume a condenser to have a certain charge due to a given applied e.m.f. to have been measured, under a condition in which the space between the plates is of an air dielectric. If a plate glass be inserted between the plates, it will be found that, for the same

applied voltage, the electrostatic charge is increased, thus denoting that a change in the dielectric material will change the capacity of the condenser.

This property is due to the density of the material or, in other words, the density of molecular structure.

For example, if the dielectric between two plates of a condenser is air and the air pressure is increased to about 250 lb. pressure between the plates, an increase in the dielectric strength will result.

Air is commonly used as the standard of comparison and is, therefore, expressed as having a "dielectric constant" of 1.

Thus, we may define the dielectric constant of any substance as the ratio of the capacitance of a condenser using this substance, to the capacitance of the same condenser with air as the dielectric.

The formula for determining the dielectric constant of any material is written

$$\frac{Cp}{Ca} = K$$

where K is the constant,

Ca the capacitance with air as the dielectric,

Cp the capacitance with another substance as the dielectric.

Various values of dielectric constants of different materials is given below.

A vacuum	0.94
Hydrogen	0.9997
Air	1.0
Carbon dioxide	1.0008
Liquid oxygen	1.478
Paraffin wax	1.99 to 2.29
Sulphur	2.24 to 3.84
Ebonite	2.6 to 3.48
Shellac	2.74 to 3.73
Quartz	4.49 to 4.55
Glass, various grades	6.0 to 10.0
Mica	6.6 to 8

The capacity of a condenser can be increased by applying any one of the following methods:

1. Increasing the area of the plates.
2. Bringing the plates close together.
3. Using a material having a larger dielectric constant.

CAPACITY OF CONDENSERS IN PARALLEL AND IN SERIES

Parallel.—Figure 75 represents a common arrangement of condensers in parallel.

Assuming each condenser to have an individual capacity of 0.002 mf., the total effective capacity will be 0.006 mf.

This can readily be seen if the three condensers in Fig. 75 are connected in parallel, in which the letter Q represents the total charge given to them, a difference of potential of E units between the points X and Y, which are the terminals of the systems, is produced.

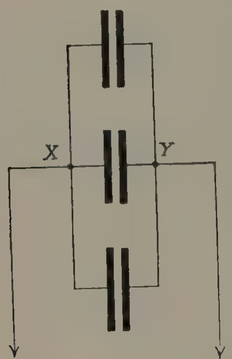


FIG. 75.—Condenser in parallel.

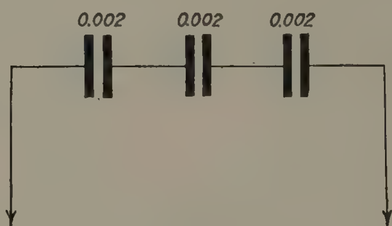


FIG. 76.—Condenser in series.

The charges in the condensers will be different, therefore, due to the increase of plate area, but the E will be the same for all of them.

Thus, if the charges Q of each condenser are added,

$$Q = q1 + q2 + q3.$$

Hence, if the total capacity of three condensers connected in parallel is the result of the addition of the three charges, the formula for condensers in parallel will obviously be:

$$C = C1 + C2 + C3.$$

Series.—Figure 76 represents three condensers connected in series, assuming each condenser to have a capacity of 0.002 mf. The total effective capacity under this arrangement will be less than the lowest of the component capacities.

The formula for condensers connected in series is expressed as follows:

$$C = \frac{C_1}{n}$$

hence $$C = 0.0006\tfrac{2}{3}\text{ mf.},$$

where n represents the number of condensers and C_1 the capacity of one (.002 mf.).

If the condensers are of uneven capacities, however, the formula would read as follows:

$$C = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}}.$$

Example.—Three condensers having capacities of 0.002 0.004 0.002 are connected in series. What is the total effective capacity?

Solution:
$$C = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}}.$$

or

$$C = \frac{1}{\frac{1}{0.002} + \frac{1}{0.004} + \frac{1}{0.002}}$$
$$= 0.0008\text{ mf.}$$

It will always be seen that whenever uneven capacities are connected in series the total effective capacity will always be less than the smallest condenser value in the circuit.

Why the capacity is reduced when condensers are connected in series will be understood by analyzing the dielectric effect of the two condensers in Fig. 77.

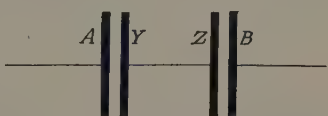


Fig. 77.—Showing condensers in series.

The plates Y and Z, being electrically connected, actually form a single plate. Assuming the dielectrics of each capacity to have a like thickness, it can readily be seen that by joining both dielectrics in a series formation, the distance between plates A and B is merely widened and, consequently, the thickness of the dielectric is increased. If each condenser has a capacity of 0.002 mf., therefore, and is connected in series, the dielectric thickness

is doubled and results in a reduction of capacity to one-half of its former value *i.e.*, 0.001 mf.

The mathematical formula for determining the capacity of a condenser under various conditions, such as changes in dielectric constants, thickness of the dielectric, and area of the plates is expressed as follows:

To find the C of any condenser:

$$C = \frac{\text{Area}}{4 \times 3.1416 \times d} \times K.$$

where d is the thickness of the dielectric, and k the dielectric constant

Energy Stored in a Charged Condenser.—It is quite obvious that it takes work, or energy, to charge a condenser, the amount of which depends upon the capacity and the voltage to which it is charged.

This energy used in charging a condenser and stored in the form of an electrostatic field between the plates is expressed by the formula

$$W = \tfrac{1}{2}CE^2$$

where C = the capacity of the condenser in farads:
E = the e.m.f. to which the condenser is charged.
W = number of joules of energy (work).

Condenser Discharge.—As stated before, when two plates separated by a dielectric are connected to a battery or to any

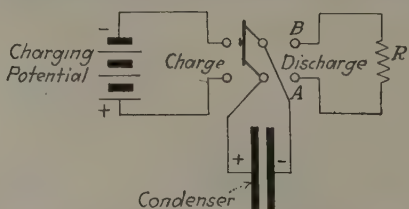


FIG. 78.—Arrangement for charging and discharging a condenser.

other source of e.m.f. a quantity of electricity will flow into them. When the difference of potential equals the applied e.m.f., no more electricity flows into the condenser and it is said to be charged. If the condenser is assumed to be in a charged condition, that is, one plate charged positively and the other negatively and disconnected from the charging source and connected with an external conductor, as in Fig. 78, the condenser will discharge

through the conductor until its energy is dissipated in heat. The discharge of the condenser is so rapid that if a meter were to be placed in the circuit it would give but one instantaneous deflection. If the discharge of the condenser through the wire could be viewed, however, it would be seen to consist of a series of discharges, first from A to B and then from B to A. The discharge of a condenser through a conductor is, therefore, said to be oscillatory. That is, the current flows from one side of the condenser into the other side and then back again. This vibration, or oscillation, will continue until an equilibrium is finally attained, due to the dissipation of the energy into heat.

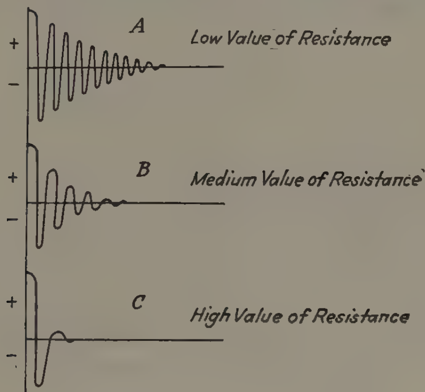


FIG. 79.—Types of damped waves.

It is thus evident that the rate of damping can be controlled by changing the resistance of the conductor through which the condenser is to discharge.

For example, if the circuit in Fig. 78 has a large value of resistance inserted in it, the condenser may actually be made to discharge so slowly, due to the resistance dissipating its energy in heat, that the discharge will not be of an oscillatory nature.

Figure 79, A, B and C, illustrate the shape of the wave or oscillatory motion produced by the different values of resistance in series with a condenser discharging.

Mechanical Analogy for a Condenser Discharge.—When a condenser is charged, the dielectric between the plates is electrostatically strained. Similarly, if the spring in Fig. 73a is assumed

to be strained beyond its normal resting position X to A, it will spring back past the point X to B and then back again almost to the point A. This will cause the spring to oscillate up and down until the energy acquired in extending it is dissipated as heat in the spring.

It will thus be seen that if the spring is of small mass and possesses good elasticity, the oscillations will be very rapid.

Similarly, the condenser is a device whereby the potential energy of the charge is gradually dissipated in heat, the major portion of which is expended in the circuit and a small part in the dielectric itself, due to the molecular friction, the result of the displacement current first flowing in one direction and then in the other.

Questions

1. What is a condenser?
2. Describe the theory of the condenser charge.
3. What is the function of the dielectric?
4. What is the unit of electrostatic capacity?
5. What materials have high dielectric constants?
6. What is the effect of connecting condensers in parallel?
7. What is the effect of connecting condensers in series?
8. Describe the nature of a condenser discharge through an inductance.
9. What effect has resistance upon the discharge of a condenser?
10. What type of frequencies can be produced by a condenser discharge?

CHAPTER XII

CHARACTERISTICS OF ALTERNATING-CURRENT CIRCUITS

The fundamental laws governing alternating circuits of the lower frequencies, namely, 60 to 1,000 cycles per second, also apply to the higher range of frequencies employed in radio transmission circuits which range from 10,000 to 15,000,000 cycles per second and higher.

The frequency of an alternating current indicates the number of complete cycles of values from zero to maximum and back to zero again, both in a positive and a negative direction of current flow. Each cycle forms a wave which appears above and below a neutral line. This wave is a graph of current or potential, amplitude plotted against time, as abscissa. In the ideal alternating-current circuit the current wave reaches its maximum value at the same instant the voltage wave reaches its crest and thus the current and voltage are said to be in step or in phase. But this can only be obtained when the circuit contains ohmic resistance alone. In alternating-current circuits, other factors, namely, inductance and capacitance, must be considered, as they bring about conditions which govern the most important functions of the ratio circuit.

Effect of Inductance.—The effect of inductance in an alternating-current circuit is to cause the current to lag behind the impressed e.m.f.; that is, the current reaches its maximum value at some instant after the voltage. This might be termed the inertia of the circuit as it is analogous to that property of a solid body such as a fly wheel which tends to keep it moving after the power is shut off, and requires additional power to get it in motion when the engine is started.

The sine curves in Fig. 80 illustrate this phenomena as it effects the electric circuit. The line *AB* represents time; and a comparison of the relative values of the curves must be made by

reading the values of the curves at a given time. Instantaneous values can be obtained by drawing a line perpendicular to the line AB at any point in its length.

As an example, find the value of the current when the e.m.f. is at zero value. From a point at which the e.m.f. curve is crossing the line AB, draw a line perpendicular to and crossing the line AB. At the point of intersection of the perpendicular line with the current curve, the value of the current is shown when the voltage is zero. The curves show that when the voltage is at zero, the current is at maximum, and if the line AB between the points of beginning and the points of ending, be divided into 360

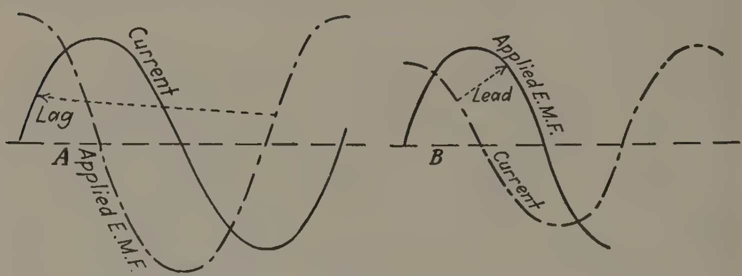


FIG. 80.—Lagging and leading effect of an alternating current.

parts or degrees it will be seen that the current in this instance lags behind the voltage exactly 90 deg. The lag of the current depends entirely upon the inductance in the circuit. The values of the curves depend on the volts and the amperes in the circuit and may be drawn to any convenient scale.

Capacitance, or the effect of condenser capacity in an alternating-current circuit, is just the opposite to that of inductance. It might be described as a force overcoming the inertia caused by inductance; and if enough capacitance is present in an alternating-current circuit, the current will lead the voltage as is shown in the sine curve B in Fig. 80. If a condenser is connected to a direct-current source the plate will take on a charge equal to the impressed e.m.f., but no current will flow. When a condenser is connected to an alternating-current source, however, its plates will receive this charge and return it to the circuit at each reversal of the voltage and current, or twice in each cycle.

Reactance is the effect of the presence of either inductance or capacitance or both of these, in an A.C. circuit. Reactance does not effect a circuit in the same way as ohmic resistance, but its presence materially changes the results of Ohm's law when applied to alternating currents. All of the energy used in overcoming ohmic resistance is dissipated in the form of heat but, in the case of reactance, practically all of the energy is returned to the circuit during the next reversal of current. In the case of inductance this energy is stored in the magnetic field surrounding the conductors and is returned when the field collapses and a slight amount of heat is generated in the condenser due to the molecular friction in the dielectric. The inductive reactance in an alternating current circuit might therefore be defined as that phenomenon whereby an opposition is offered to the flow of alternating currents due to the counter electromotive force of self-induction. In other words, the *inductive reactance* due to self induction must be "overcome" by the e.m.f. just as it is necessary for the e.m.f. to "overcome" a resistance in a direct current circuit in order to allow a current flow. The student should refer freely to Chapter III on self-induction in order to obtain a clear understanding of this subject.

The capacitive reactance in an alternating current circuit is the opposition offered by the condenser to the flow of an alternating current. It is similar to inductive reactance but not the same. That is, their effects are 180° apart. It is therefore possible that one may neutralize the other. Should this take place then the circuit would be called a *resonant circuit*. However, if the inductive reactance is greater than the capacitive reactance then the current will *lag* behind the applied e.m.f., but if the capacitive reactance is greater than the inductive reactance, then the current in the circuit will *lead* the applied e.m.f. There are two kinds of reactance in alternating current circuits, *i.e.* positive and negative reactance. The former is the effect of the inductance while the latter is the effect of the capacitance.

Impedance is the resultant effect of resistance and reactance, and is found by taking the algebraic sum of the resistance and reactance. Since these elements of an alternating current circuit act at right angles to each other, their resultant effect is the hypotenuse of a triangle whose base and altitude correspond to the

resistance and reactance, respectively. This is expressed by the formula

$$Z = \sqrt{R^2 + X^2} \text{ where } Z = \text{impedance, } R = \text{resistance (ohmic).} \quad X = \text{reactance}$$

In direct currents, Ohm's law is expressed as

$$I = \frac{E}{R},$$

but in alternating currents it is expressed as

$$I = \frac{E}{Z}; \text{ or } I = \frac{E}{\sqrt{R^2 + X^2}}$$

where

I = current in amperes.
E = volts.
R = ohms.
X = reactance in values of inductance and capacitance.

Power Factor.—In direct-current circuits the power, expressed in watts, is found as follows:

$$\text{Watts} = \text{volts} \times \text{amperes}.$$

In alternating current this power is found by the formula

$$\text{Watts} = \text{volts} \times \text{amperes} \times \frac{\text{resistance}}{\text{impedance}}.$$

The term,

$$\frac{\text{resistance}}{\text{impedance}}$$

is called the power factor of the circuit and is expressed as a decimal lying between zero and one.

A circuit with resistance only has a power factor of 1 or unity and a circuit having resistance, capacitance, and inductance usually has a power factor below unity. A circuit having resistance, capacitance, and inductance, however, may have unity power factor if the capacitive reactance equals the inductive reactance at a particular frequency, when the resultant reactance is zero and only resistance is effective in the circuit. The power formula for alternating currents is expressed as follows:

$$\text{Watts} = I \times E \times \text{power factor}.$$

Also,

$$I = \frac{W}{E \times \text{power factor}},\ E = \frac{W}{I \times \text{power factor}},$$

$$\text{and power factor} = \frac{W}{I \times E}.$$

Resonance.—Resonance is one of the most important characteristics that have to be studied in connection with radio circuits. All of the above characteristics of the alternating-current circuit must be understood if a clear understanding of resonance is to be had. Figure 81 shows the simplest oscillating circuit. It contains resistance, inductance, and capacitance. It is the simplest of radio circuits. A circuit of this kind is said to be "resonant" when its reactance is zero. This means that the reactance introduced in the circuit by the inductance must be counteracted by a negative reactance introduced by the capacitance. In other words, the capacitance and inductive reactance must balance one another.

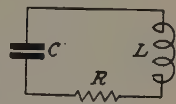


Fig. 81.—Simple oscillatory circuit.

Inasmuch as the reactance of both the condenser and the inductance varies with the frequency of the applied alternating current the values of the capacitance and inductance will vary for resonance at different frequencies. A study of the table given below taken from "The Principles Underlying Radio Communication," U. S. Signal Corps, will show how the inductance coil and condenser reactance effect is changed with the frequency. These measurements were taken from a circuit similar to Fig. 81, in which the value of the inductance coil, hereinafter referred to by the symbol L, was 500 microhenries and the capacitance value being 0.005 mf.

Frequency, cycles per second	Reactance of coil, ohms	Reactance of condenser, ohms	Total reactance, ohms
60	0.188	−530,000	−530,000
1,000	3.142	−31,840	−31,837
100,000	314.2	−318.4	−4.2
100,700	316.23	−316.23	0
1,000,000	3,142	−31.84	−3,110

With the above values of capacitance and inductance, the circuit is resonant when the frequency is 100,700 cycles per second. The table shows that the reactance is zero at this point. Notice that the inductance and capacitance are equal in reactance effect and the resultant effect is therefore zero.

The value of the oscillating voltage drop in a resonant circuit is much greater than the impressed voltage. In a radio circuit, it is possible to have the drop across the inductance and condenser four-hundred times greater than the impressed voltage. To get a maximum current flow, it is necessary to tune the circuit to the resonance frequency. In other words, the inductance and the capacitance must be in such relation, one to the other, that the combined reactance of both is zero. The circuit is then said to be resonant.

Mechanical Analogy of Resonance.—When soldiers march over a bridge the order is given to "break step." This is to safeguard the bridge by removing the rhythmical impulses or "pushes" which would result were the soldiers marched over "in step." Every object has a frequency of vibration, therefore, the bridge has a certain frequency of vibration. If the soldiers were marched over "in step" and the weight of the men imparted in shocks to the bridge at its frequency of vibration it would start to vibrate and these vibrations would increase in amplitude until the struts and beams of the bridge gave away. The frequency of vibration of the bridge corresponds to the resonance frequency in the oscillating circuit. It is easily imagined how the vibrations of the bridge would increase as the men continued to march. These vibrations would get so violent that finally the bridge would give way, although the individual "power" behind each impulse or shock is the same. This is analogous to the increased value of the oscillating current in the circuit in Fig. 81 over the impressed voltage which would in some cases be four-hundred times as great. In a radio circuit, if resonance causes too great an increase in current value the condenser dielectric would be punctured.

The Application of Resonance to Various Forms of Radio Circuits.—Figure 82 illustrates a fundamental radio circuit in which the inductance L, the capacitance C, and the resistance R are connected across an alternating e.m.f., of a certain frequency. It will be seen from Fig. 80 that an inductance will create a lagging

effect upon the current flow and the condenser a leading effect. If the inductive reactance of the coil L for a given frequency, say 100,700 cycles per second, is 316.23 ohms and the capacitive reactance for the same frequency is 316.23 ohms, then, in accordance with the theory of alternating currents, if the current leads the voltage by 90 deg., due to the capacitance in the circuit, and the current lags 90 deg. behind the voltage, due to the inductance; it can be seen that the two values will neutralize each other and consequently will result in an effective value of zero reactance.

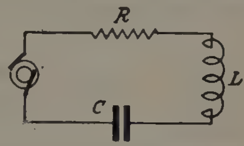


FIG. 82.—Series resonance circuit.

Impedance.—From the above relation it may be seen that the inductive reactance $2\pi FL$ and the capacitive reactance $\frac{1}{2\pi FC}$ can be proven by the use of the two formulas.

Thus, if the alternator frequency F is gradually increased, the inductive reactance increases, while the capacitive reactance decreases. If, therefore, in the above formulas the values of either FL or FC are increased, the total reactance will at all times be equal to the difference of the two. Hence, if the inductive and capacitive reactances are equal for a certain value of frequency then the resultant reactance is zero. Thus,

$$2\pi FL = \frac{1}{2\pi FC},$$

therefore, if the values of the inductance and capacity are known the frequency may be determined by the following:

$$F = \frac{1}{2\pi\sqrt{LC}}$$

and is called the "natural frequency" of the circuit.

If the natural frequency of the circuit is equal to the impressed frequency, the total impedance Z will be practically zero, and a maximum of current will flow in the circuit. Consequently, when this condition prevails the circuit is said to be in complete "resonance" or "tune" with the impressed e.m.f. Thus at resonant frequencies the current is a maximum in all circuits and is equal to $I = \frac{E}{R}$.

Figure 83 is slightly different from the previous circuit in that the capacity C is connected directly across (shunt) the inductance L. Therefore, when the applied alternating e.m.f. is impressed across each branch L and C of the oscillatory circuit a current will flow in the two branches but in opposite directions, providing, of course, that the alternator frequency is resonant with the free oscillation frequency of the circuit. Thus, the sum of the current in the external circuit will be very nearly zero while that flowing in the oscillatory circuit itself will be at a maximum.

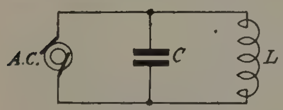


FIG. 83.—Parallel resonance circuit.

The theoretical function of this circuit would be as follows:

First, assume that the inductance L has a value of self-inductance large enough to prevent a short-circuit of the alternator. It will be remembered that a varying magnetic field about a coil produced by an alternating e.m.f. will tend to oppose that e.m.f. depending upon the number of turns on the inductance or the rate of change in the frequency.

Consider then, the applied e.m.f. of the alternator charging the condenser C. As the voltage rises from a zero to a maximum value the condenser charges. Then, as the alternator voltage decreases, the condenser discharges through the inductance and continues to oscillate. But if the alternator frequency is constant, the e.m.f. impressed on the condenser by the alternator will be in phase with the oscillating e.m.f. at the condenser as a result of the oscillation. Thus with the alternator maintaining a constant e.m.f. at the condenser at a steady value, it is seen that the alternator functions as a "driver" and tends to maintain oscillations of a continuous character (undamped wave, Fig. 84a).

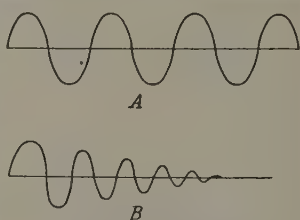


FIG. 84.—Damped and undamped oscillations.

If the condenser discharge took place with the alternator disconnected, however, then the oscillations would be of a discontinuous or "damped" character (Fig. 84b), due to the resistance losses caused by energy dissipation in the form of heat.

This does not mean that there is no resistance loss in Fig. 84a but, due to the "driver" action of the alternator, the loss is

compensated for and the wave is kept continuous. The loss due to resistance in a continuous wave circuit, therefore, results merely in a decrease in the amplitude of the wave.

Questions

1. What factors, in addition to resistance, are sometimes found in an alternating-current circuit?
2. What effect has inductance in an alternating-current circuit?
3. What is meant by the term inductive reactance? Capacitive reactance?
4. What effect has an increase of frequency upon the inductive reactance of a circuit?
5. What is the formula for finding impedance?
6. Define resonance.
7. A circuit has a capacitive reactance of 1,000 ohms and an inductive reactance of 1,000 ohms at a certain frequency. What is the effective reactance?
8. Draw a diagram of a simple oscillatory circuit.
9. How can the frequency of the above circuit be decreased?
10. Draw a diagram of two oscillatory circuits inductively related.

CHAPTER XIII

PRINCIPLES OF THE SPARK TRANSMITTER

Oscillating Condenser Discharge through a Spark Gap.— Up to the present time the effect of a condenser in a circuit in which alternating current flows has been considered. The condenser effect has been contrasted with the inductance coil effect. This was necessary in order that the term "resonance" might be understood. A condenser in a radio circuit, however, functions in another very important way which as yet has been untouched.

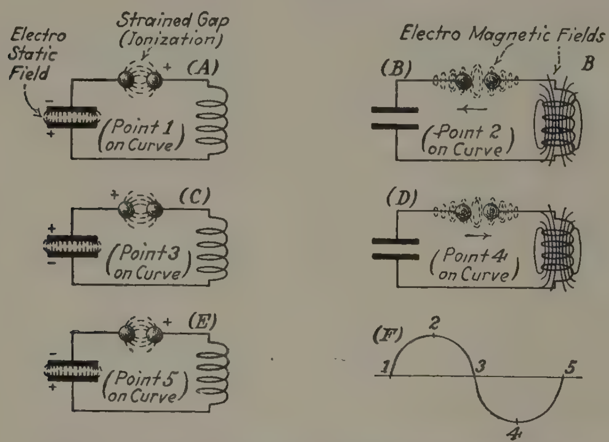


Fig. 85a.—Complete cycle of a condenser charge and discharge.

This function of the condenser is to absorb a charge and then discharge through the oscillating circuit, setting up ether waves as it does so. A study of the various conditions of the condenser during discharge is shown in the illustrations in Fig. 85a.

The condenser is assumed to be fully charged in A; at the start of the discharge through the spark gap the energy is all electric. Notice the polarity of the plates. At the end of the first quarter the energy is all magnetic. Now refer to the sine curve at the

bottom of the figure which shows the value of the oscillations as the condenser continues to discharge. Point 1 shows when the condenser commenced to discharge, point 2 is the end of the first quarter; the energy is all magnetic, and remains that way for an instant until the current starts to decrease. The decrease continues until the end of the second quarter, point 3, when the condenser is again in the condition it was at 1; and the energy is all electric. There is, however, a marked difference in its actual condition. Refer to the graphic illustration: The polarity of the plates have changed and the amount of potential current in the condenser is less because part of the original value has been dissipated in the form of light and heat at the spark gap. It now commences to discharge in the opposite direction and does so until the end of the third quarter, point 4, when the energy is again all magnetic but in a reversed direction. This will be noticed in the reversed direction of the field, as shown by the reversed arrows. The discharge continues to point 5, which is the end of the complete cycle of discharge. Illustration E shows the condenser to this point; the polarity of the plates is the same as at the start; the energy is all electric but less in amount. The discharge continues; the number of complete cycles the condenser is able to make before it is completely discharged depends upon its capacity, external inductance and resistance. Every alternation becomes smaller and smaller in amplitude because of the energy dissipated in the circuit, due to resistance and the energy lost in the form of light and heat in the spark gap. This difference in the amplitude of the oscillations is called "damping," and a condenser used with an inductance in a circuit as above described generates a damped wave.

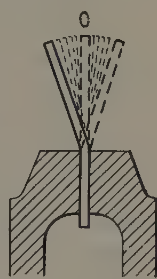


FIG. 85*b*.—Mechanical analogy of a condenser discharge.

A good mechanical analogy of the damped oscillations described above is shown in Fig. 85*b*. This shows a steel spring fixed in a clamp. If the spring is pulled over slightly to one side and then released with a snap, it will vibrate. At the beginning the vibrations will be over a comparatively long sweep and, as time goes on (seconds), the sweep of vibration becomes less and less until it finally comes to rest. If a piece of lead pencil were

fastened to the spring and a strip of paper so fixed that it would move under the point as the vibration of the spring was going on, a line would be traced which would be similar to the sine curve of the damped wave at the bottom of Fig. 84.

Ether Waves.—The ether waves sent out by the radio transmitter are of the same character as light waves. The difference between light waves and radio waves is in their length only. Ether waves 36×10^{-6} cm. long give the sensation of violet light, 45×10^{-6} cm. long the sensation of blue light, and so on through all the different colors of the spectrum, until waves 80×10^{-6} cm. long give the sensation of red light. Ether waves longer than this do not affect the eye. Ether waves can be used in a practical way for radio from 20 m. up to perhaps 50,000 m.

The term 10^{-6} is an abbreviated method of expressing a long decimal. The negative exponent -6 indicates that the number 10 is to be carried to a position six places behind the decimal point and could be shown thus 0.0000010.

Ether waves regardless of their length travel at the rate of 300,000,000 m. or 186,000 miles per second. The longer wave lengths used in radio travel through a stone wall a foot or two thick as easily as the shorter ether light waves travel through a pane of glass.

Dr. A. A. Michelson, of the University of Chicago, has recently determined a new value with an accuracy that makes all previous work on the subject obsolete. Dr. Michelson's paper was published in full in the *Astrophysical Journal* for January 1927. In there he gives the final results for the velocity as 299,796 km. per second.

Converting this figure to English units, it equals 186,284.24 miles per second. It is believed, of course, though not definitely proven, that radio waves and all other such waves travel with the same velocity.

Damped Wave.—From the description of the oscillatory discharge of a condenser, a clear understanding of the damped wave is obtained. The word "damp," as used in connection with a radio wave, means to choke or to stifle, to die out. The damped wave is choked off or stifled, according to the characteristics of the circuit in which it is oscillating. Some circuits cause the wave to damp out more rapidly, than others. In Fig. 86 is shown three

different types of damped waves; notice the top curve in which case the damping is slight; the second curve is slightly more damped; while the bottom curve shows an oscillation which is very quickly *extinguished*, or highly damped.

Undamped Wave.—The damped wave decreases in amplitude because the source of its energy is not steady; the condenser charging and discharging periodically does not charge the oscillating circuit with the same amount of current for each alternation. On the other hand, the undamped wave has a zero decrement (no damping), and would have equal energy in each

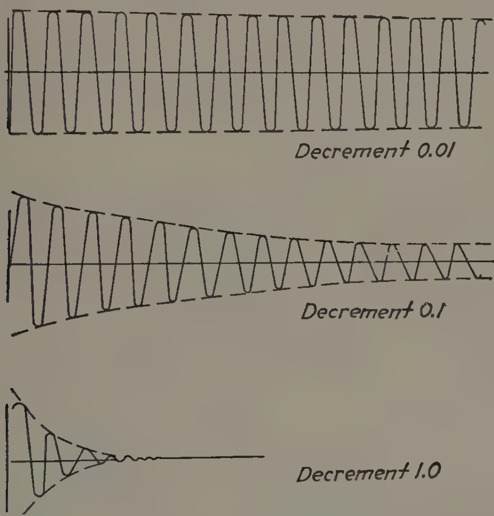


FIG. 86.—Free oscillations showing decrement.

alternation. A curve of a damped wave would, therefore, look like Fig. 84*b*.

Undamped waves are generated in a way quite different from the damped wave. The damped wave is generated by the oscillatory discharge of a condenser; the undamped wave is generated by continuous wave generators such as the vacuum tube, the arc and the high-frequency alternator.

Decrement.—The word "decrement" means loss. The loss of energy in damped oscillations causing a decrease in the amplitude of the oscillations is the decrement in the wave. The decrement in a circuit depends directly upon the resistance and inductance in

the circuit. In Fig. 86, each succeeding alternation has a smaller amplitude than the preceding one. The ratio of the amplitude of any oscillation (alternation) to that of the one which follows it is called the "degree of damping," or simply "decrement," and is found by taking the Naperian logarithm of the reciprocal of the ratio given above. This is a problem for the radio engineer and is not required of the ratio operator. It is, however, very important that the operator understand the theory underlying this measurement. The decrement of a circuit is important because if it is too high it will result in what is called a "broad wave," one which causes much interference in the receiving circuit because it is difficult to tune it out. This is such an important point that the United States government has included in the Act to Regulate Radio Communication the following regulation.

At all stations the logarithmic decrement per complete oscillation in the wave trains emitted by the transmitter shall not exceed two-tenths, except when sending distress signals or signals and messages relating thereto.

The oscillating circuit generating the damped waves in a radio transmitter must be so designed that it does not cause too high a decrement to the radiated wave. A study of these characteristics will be made when these circuits are studied. The higher the decrement, the smaller the number of oscillations taking place before the group of oscillations during one complete discharge of the condenser die out. Undamped waves have zero decrement and the oscillations are of constant amplitude as long as they are generated. The regulation specifies that a decrement exceeding two-tenths (0.2) is prohibited. As a matter of information, the number of oscillations for a decrement of 0.2 is twenty-three; therefore, the bottom curve in Fig. 86 has much too high decrement for a transmitting circuit, as the number of oscillations is six, after which all of the energy in the wave has been dissipated. The two upper curves are satisfactory, the decrement of the upper being 0.01 and the lower 0.1, both less than the limit of 0.2 prescribed in the law. Methods of measuring decrement will be taken up later.

Closed-circuit Oscillator.—The closed-circuit oscillator of the radio transmitting set is essentially the same as Fig. 85*a*. It

consists of a condenser, an inductance, and a spark gap. The spark gap acts as a sort of valve, opening the circuit automatically when the condenser has discharged, and then allowing the fully charged condenser to break it down, at which time the jumping of the spark across it completes the circuit through which the condenser discharges and generates oscillations. An elementary diagram of the circuits in a radio transmitter is given in Fig. 87. The motor drives the generator which supplies a low-frequency alternating current to the primary of the power transformer. This is stepped up several thousand times by the

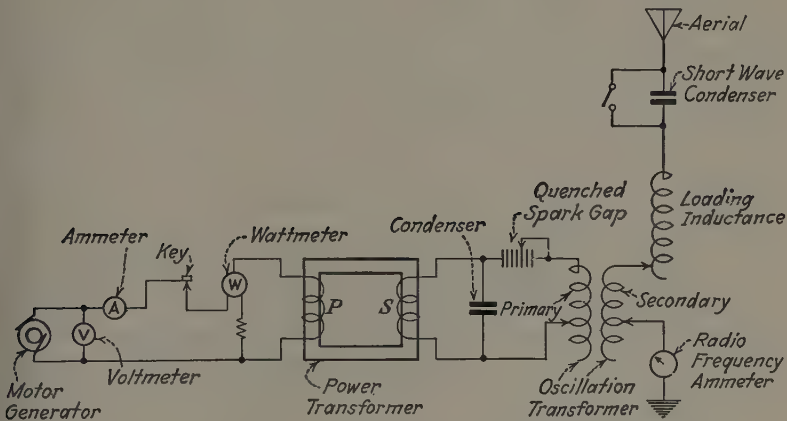


FIG. 87.—Elementary transmitter.

secondary of the power transformer which is connected directly to the condenser. If the alternator generates 500 cycles the secondary of the transformer charges the condenser one thousand times per second and the condenser in turn discharges that many times across the spark gap. The frequency of the generator, therefore, directly affects the spark or group frequency. In discharging, the condenser sends a current through the primary of the oscillation transformer L_1 (to be described later) and sets up oscillations in the closed oscillatory circuit. This circuit consists of the condenser, spark gap, and the primary of the oscillation transformer. Remember, every oscillatory circuit must have capacitance and inductance. The amount of inductance is variable and is so shown in the diagram by the arrow head con-

nection on the lower lead. A closed oscillatory circuit is a poor radiator: it does not send out waves of any marked amplitude because of its concentrated inductance and capacity.

Open-circuit Oscillator.—The open oscillatory circuit consists of the secondary of the oscillation transformer, the aerial, and the ground. This circuit is a good radiator of waves because capacity and inductance are not concentrated as in the closed-circuit oscillator. In the open oscillating circuit the capacity consists of the aerial and the ground. The aerial acts as one plate and the ground as the other. It is easily seen that the electrostatic field is not concentrated. This very condition makes it a good radiator. The inductance of the open oscillatory circuit is both distributed and concentrated. It is concentrated in the secondary of the oscillation transformer but distributed in the leads of the aerial and the ground.

DIRECTION OF ELECTRIC AND MAGNETIC LINES OF FORCE

The magnetic lines of force surrounding a conductor carrying an e.m.f. take a circular position around the conductor as shown in the Fig. 85*a*. These lines of force are like so many rings around the wire. They have a definite direction depending upon the direction of the current and change direction if the direction of the current is changed.

Electrostatic lines of force take a position at right angles to the electromagnetic lines described above. They do not form a circle around the charged body but are rather straight lines stressing to pass from one plate of a charged condenser to the other. Any two bodies carrying electrostatic charges form a condenser, whether or not these two bodies be plates; they may be two parallel wires, or the aerial and ground.

Propagation of Waves.—The waves from the transmitter which are sent out to the receiving station are propagated from the open oscillatory circuit and an explanation of the theory of this action will now be given.

Think of the aerial as one plate of a huge condenser and the ground as the other. This condenser charges and discharges in exactly the same way that the condenser in the closed circuit does, which was explained in connection with Fig. 85*a*. In the

closed oscillating circuit, however, the capacity is concentrated, the plates are close together, and this accounts for a vast difference in the radiating qualities of the two circuits. As the discharges proceed, notice that the polarity of the plates changes. Thus, the closer the two plates of a condenser the more concentrated will be the electrostatic lines of force, and, therefore, very little energy will be radiated. If, however, the plates are separated the electrostatic field area will be increased and a greater radiation of energy will result. Now in the open oscillatory circuit the plates (aerial and ground) are relatively farther apart. Hence, when the open circuit is excited an electrostatic field is created between the aerial and ground. This field is constantly moving at a high frequency due to the primary circuit high frequency excitation and therefore produces periodic polarity changes on the antenna and ground plates. This moving electrostatic field, or strain, will produce an electromagnetic field and, in turn, the electromagnetic field will produce an electrostatic field and the two components will support one another in the radiated wave. Hence, the constant production of these two fields results in an expenditure of energy (radiation) in wave form.

Frequency and Wave Length.—The rapid charge and discharge of the oscillatory circuits radiates currents of high frequency. Frequency is expressed as the number of cycles of alternating current occurring in a second. Audio frequencies range between 30 and 10,000 cycles per second and radio frequencies range between 10,000 and 3,000,000 cycles per second, or over. There is no distinct dividing line between these two frequencies, but they are usually referred to according to the above classification. Frequency varies inversely with wave length. This is an important thing to understand and an easy thing to imagine.

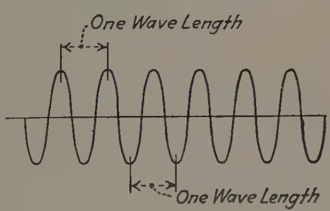


Fig. 88.—Illustrating one wave length.

The amount of inductance and capacity in a circuit affects directly the wave length or oscillation frequency. If either one or the other is increased or decreased the wave length is varied accordingly. Figure 88 illustrates one wave length.

If the value of the inductance L and capacity C is known, the wave length of an oscillatory circuit may be found by the formula:

$$\lambda = 1885\sqrt{LC}.$$

The symbol λ (lambda) signifies the wave length in meters (39½ in.). The frequency may be found when the values of L and C are known by the following formula:

$$F = \frac{1}{2\pi\sqrt{LC}}, \qquad \pi(\text{Pi}) = 3.1416.$$

The values for L and C in the above formulas are in microunits, *i.e.*, microhenries and microfarads.

RELATION BETWEEN WAVE LENGTH AND FREQUENCY

Wave length in meters	Frequency in cycles per second
150	2,000,000
200	1,500,000
300	1,000,000
450	667,000
600	500,000
750	400,000
1,000	300,000
2,000	150,000
3,000	100,000
6,000	50,000
8,000	37,500
10,000	30,000
15,000	20,000
20,000	15,000

It will be noticed that wave length $= \dfrac{300{,}000{,}000}{\text{frequency}}$, or $\lambda = \dfrac{N}{F}$,

where

N = speed of electromagnetic waves in meters.
F = frequency in cycles per second.

Coupling.—The energy from the closed oscillatory circuit is induced in the secondary or open oscillatory circuit by virtue of the coupling of the circuits. The circuits are in such relation, one to the other, that there is an electromagnetic induction between them. There are three methods of coupling, shown in Fig. 89.

Coupling of the oscillatory circuits is accomplished through the oscillation transformer or by means of condensers.

The primary circuit is the one into which the e.m.f. is applied and the other is the secondary circuit.

Direct coupling is the method into which the primary and the secondary have several turns of the oscillation transformer in common. In Fig. 89, turns x, are in common.

Inductive coupling exists when the transfer of energy is by electromagnetic induction only, between the primary and secondary coils of the oscillation transformer.

Capacitive coupling exists when the transfer of energy from the primary to the secondary circuit is through the electrostatic lines of the coupling condenser.

Circuits are said to be *closely coupled* when a small change in the current characteristics in one produces an appreciable change

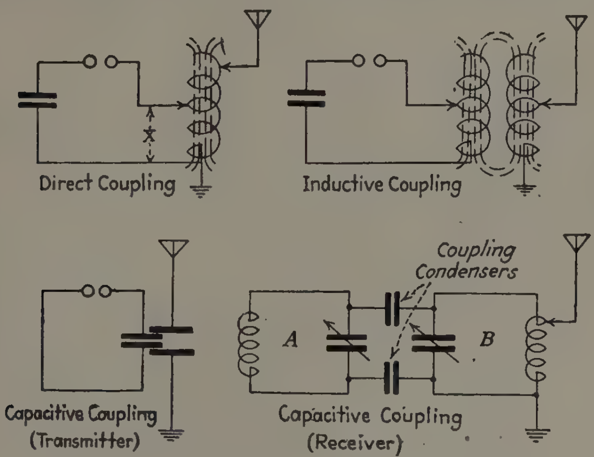


FIG. 89.—Methods of coupling the transmitter.

in the other. This is also referred to as *tight coupling*. On the other hand, when a change in one circuit produces little effect on the other the coupling is said to be *loose*. The coupling between two inductively coupled circuits is made looser by increasing the distance between the coupling coils, namely the primary and the secondary.

The coupling in a direct-coupled circuit is made *tighter* by increasing the amount of inductance which is common to both circuits. In an inductively coupled circuit the coupling is made *closer* or *tighter* by moving the coils nearer or increasing the inductance in each.

In some types of receiving apparatus a combination of capacity and inductive coupling is used. Only high-frequency radio circuits are referred to as being coupled. For instance, the secondary of the power transformer is not said to be coupled to the primary; it is merely in an *inductive relation* to it. In Fig. 89, there are two illustrations of capacity coupling, both of which work on a transference of energy by means of electrostatic lines of force.

Practical Operation of Spark Transmitter.—The alternating-current generator is the source of all the power utilized by the radio transmitter, which it furnishes in the form of alternating current at voltages ranging from 100 to 500 for different types of machines, and at frequencies ranging from 60 cycles in the earlier types of machines to 500 cycles, which is now almost always used in modern radio sets.

The key controls this power circuit. When it is closed, as in making the dots and dashes of the code, an alternating current is sent through the primary of the transformer where it is stepped up in voltage, but not in frequency, to voltages ranging from 10,000 to 25,000. This high voltage charges the transmitting condensers and when the condensers are charged to a sufficiently high voltage or difference of potential, a spark jumps the spark gap in the closed oscillation circuit, so-called, consisting of the condensers, primary of the oscillation transformers, and the spark gap.

In Fig. 87 the gap is called a "quenched" gap, which is one of the types of spark gaps which will be discussed later. The gap is, of course, always set to such a length that it will not allow a breakdown of the transformer secondary safety gap (described under Power Transformer) or the condenser. The electrical energy taken from the alternating-current generator is, therefore, utilized in charging the condenser in much the same manner as an air compressor would do work in running up the air pressure in a tank. If a compressed-air tank had a safety valve which would pop at a certain pressure, it would act in much the same manner as the spark gap acts in a radio transmitter as it breaks down at a certain voltage, depending upon the length of the gap, and permits the condenser charge to oscillate in the closed oscillatory circuit mentioned above.

The frequency of this oscillating current is determined by the amount of capacity and inductance in the circuit. Provision is

made for changing the frequency and consequently the wavelength of the transmitter by varying the inductance in the primary of the oscillation transformer.

The energy in the closed oscillatory circuit is transferred to the antenna circuit by electromagnetic induction exactly the same as in any transformer, except that we know the most efficient transfer is made when the two circuits are *tuned* or in resonance. The rapidity of this transfer of energy is also determined by the closeness or coupling of the coils. Provision is, therefore, made to vary this coupling and for tuning the antenna circuit by variation of the coupling inductance (secondary) and of the loading or aerial tuning inductance (see Fig. 87).

When the aerial circuit is properly coupled and tuned there will be a condition of most efficient transfer of energy and the aerial ammeter reading will be a maximum. The ideal spark gap would be one which immediately regained its original characteristics after each discharge and required the same voltage for the next break down of the gap. This would prevent the energy which is transferred to the antenna circuit at the first discharge of the condenser across the gap, and which is utilized in charging the antenna capacity from being partly transferred back to the closed circuit by the breaking down of the gap, by a lower voltage at the second and following discharges.

As will be brought out, this condition actually existed in the earlier types of gaps, and was one of the problems of the development of efficient radio transmitters. The earlier transmitters used spark gaps that permitted retransfer of the energy in the two oscillation circuits, until much of it had been expended in the resistance of the two circuits in the form of heat, and some, of course, by radiation when the antenna circuit was oscillating.

It should be noted that the condenser is charged at the frequency of the alternating-current generator, but discharged at a much higher radio frequency determined solely by the oscillation circuits. The condenser is, therefore, in effect not only the tank in which the electrical energy is stored, but in conjunction with the inductance is also a frequency changer.

Transmitter Circuit.—The modern radio transmitter which is shown in Fig. 87 has, in the order represented in the diagram, the following apparatus:

1. Motor generator.
2. Starting devices (not shown in diagram).
3. Protective condensers (not shown in diagram).
4. Power transformer.
5. Meters.
6. Condenser.
7. Spark gap.
8. Oscillation transformer.
9. Radio frequency ammeter.
10. Short wave condenser.
11. Aerial tuning inductance.
12. Key.

A complete study of this set will now be made beginning at the direct-current mains and taking in all the apparatus to the aerial and ground.

Spark transmitters divide themselves into two general types: (1) spark type, using quenched or rotary spark gaps; or (2) impact type, using the Chaffee, or similarly constructed, gaps. This latter type gap consists of two thin sparking surfaces of tungsten welded to copper backs and operates in air. These gaps have a micrometer adjustment and may be varied to the one-thousandth part of an inch. Such a gap is shown on the transmitter in Fig. 190*a*.

Range of Transmitters.—Spark transmitters in commercial service range in power from ½-kw. sets used on small freight vessels to 5-kw. sets used in some of the larger shore stations. The range of these sets depends entirely on conditions but, generally speaking, the more elaborate the aerial spread the greater the range. Weather conditions also affect the range very materially. A ½-kw. set may be counted on conservatively to transmit 100 miles in the daytime and 150 miles at night; 1-kw., 150 miles by day, 300 miles by night; 2-kw., 200 miles by day, 400 miles by night; and 5-kw., 300 miles by day, 600 miles by night. The range in the winter season is greater than in the summer.

Plain Aerial Transmitter.—Before beginning an explanation of the modern transmitter, a brief historical sketch will be given of the early type transmitter, as employed by Marconi, DeForrest, and other pioneer radio engineers. The first practical transmission of radio telegraph signals was sent out from a transmitter

consisting of nothing more than a condenser across which was connected a spark gap, the spark gap being connected in series with the aerial and the ground, as shown in Fig. 90. The wave length of this set depended entirely upon the length of the aerial and the leads connecting the aerial and ground to the spark gap. The wave emitted was exceedingly broad due to the resistance of the spark gap which was directly in series with the open oscillating circuit. It was impossible to vary the electrical length of the aerial because of the absence of tuning inductances, and the efficiency and range were low due to the high losses present in all parts of the circuit.

In time, the tuning inductance was introduced. This first took the form of an inductance coil connected in series with the aerial and fitted with a movable contact which allowed a variation of the number of turns employed and consequently allowed a change in wave length. This single-contact coil was followed by the two-contact type as shown in Fig. 89, which provides a variation of the inductance in the open and closed oscillating circuits. Later it was found that, by employing an inductive type of tuning the inductance or oscillation transformer, the damping effect between two oscillatory circuits was considerably decreased and thereby sharper tuning was made possible. The various methods of coupling are all shown in Fig. 89. Modern practice calls for a method of coupling which allows a very sharp tuning. The inductive method is the most commonly used because it provides a means of adjusting for a decreased damping of the oscillations. The plain aerial transmitter is now only used for emergency transmitting equipment employing the well known 10-in. spark coil (induction coil with interrupter).

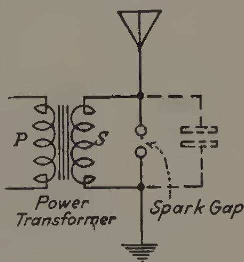


FIG. 90.—Simple spark transmitter.

Note.—As part of the explanation of each piece of apparatus on the typical set here described, the rating or numerical value of the instrument or piece of apparatus will be given, *i.e.*, condenser capacity, inductance coil values, meter ranges, etc. It is important that the student have an idea of these values and a comprehensive understanding of the set as a unit.

Motor Generator.—All of the commonly used types of spark sets (except the new Federal type) employ A.C. As all ships have direct-current generators, a motor generator is necessary. Figure 23 is an illustration of a type of motor generator commonly used with commercial equipments today. The function of the motor generator is to transform the direct current of the ship's mains to alternating current required by the power transformer. In shore stations where alternating current is available from the mains of the local power company, a motor generator is unnecessary. The direct-current available is usually 110 volts. For a 2-kw. set a 4.3 or 5-hp. motor is employed. On the same shaft is connected the generator which delivers 120 volts alternating-current at a standard frequency of 500 cycles. The generator is also a 5-hp. machine and the unit as a whole runs at a speed of 3,000 r.p.m. Speed is controlled by a field rheostat.

The motor generator is started either by a hand starter or by an automatic starter, both of which were described in a previous chapter.

When the strength of the field or flux which is surrounding the armature is weakened, there is less magnetic reluctance for the armature to overcome, therefore, it revolves faster. To increase the speed of the motor generator, therefore, turn the motor field rheostat in the direction of *increase resistance.* To decrease the speed turn it in the opposite direction. From the foregoing it is shown that the function of the motor field rheostat is to control the speed of the motor generator.

The function of the generator field rheostat is to control the alternating-current voltage delivered by the machine.

The frequency of the alternating current is dependent entirely upon the speed of the machine, therefore, lowering the speed lowers the frequency and vice versa. Remember also that the spark frequency is dependent upon the alternator frequency. Hence, the motor rheostat which controls the speed of the motor also controls the spark frequency. The tone of the spark depends upon its frequency; it therefore follows that an adjustment of the motor field rheostat would result in a change in the tone of the spark. Trace out the reasoning explained above, as it is impor-

tant in connection with the practical operation of a radio transmitter.

Lowering the speed of the motor generator lowers the voltage as well as the frequency. That this should happen is obvious.

Protective condensers are installed to protect the motor generator against the possibility of a kick-back from the high potential high frequency current flowing in the transformer secondary. If this should occur, and no protective condensers were provided, the windings of the alternator armature might burn out. Figure 69 shows the latest type of protective condenser. All modern installations are equipped with this or a similar type. There are three connecting terminals on each device: the center one is connected to the ground and the other two are connected across the apparatus to be protected. On a steel vessel a ground is made to the hull of the ship, while on a wooden vessel a large copper plate is fastened to the hull beneath the water line and a connection is made to the propeller through its shaft, which is metal. Due to the fact that in a rough sea the propeller is not always under water, the metal plate to the hull is necessary.

A protective device unit is usually provided to protect the motor generator and another to protect the primary windings on the transformer.

The student should understand the purpose and function of this device and note its positions in the diagram of the complete transmitter (Fig. 161).

If a high-frequency kick-back does occur the condenser will absorb the discharge and in turn discharge it across the safety spark gap with which it is fitted. If the potential of the discharge is too great the dielectric of the condenser will be punctured and it must be replaced. When the dielectric is punctured, it ceases to be a dielectric and the spark jumps through the hole. The modern type of protective device shown in the illustration is self-healing and in practice they have been found to heal themselves dozens of times before becoming useless.

Power Transformer.—Inasmuch as the condenser cannot be properly charged with a voltage less than 10,000 to 20,000 volts, a step-up transformer is necessary. It will be remembered from the previous discussion of the power transformer that the ratio of transformation depended entirely upon the ratio of the turns in

the primary to the turns in the secondary, *i.e.*, if the number of turns in the secondary were ten times the number of turns in the primary the voltage would be stepped up ten times. The primary is the winding into which the current to be transformed is impressed and the secondary is the winding from which the transformed current is taken. It is a common error on the part of the novice to think that the primaries of all transformers have less turns than the secondaries; this is, of course, true of the power transformer in the transmitter of a radio set, but would not be true were a transformer used to light the filament of a 6-volt vacuum tube from a 110-volt lighting circuit.

The power transformer is fitted with a safety-spark gap which is fitted directly to its terminals. This gap is set at a certain distance which is fixed and must not be varied. The maximum voltage which the transformer can handle will not jump this gap, but should this value be exceeded, the gap acts as a safety valve and provides a path of discharge for the excess pressure (voltage). If the safety gap was not provided, the voltage would jump at the next easiest place, which might be in the windings of the secondary, burning them out and making the transformer useless. From what precedes it is easy to see that the main spark gap of the transmitter must not be set wider apart than the safety gap as electricity always takes the shortest path.

Meters.—The meters on a radio transmitter are as important to the successful operation of the set as are the speedometer and oil gage on an automobile. They tell what is going on in the various circuits. All of the meters used were described in principle in Chap. VIII, and the student is advised to refer frequently to that section while studying this one.

The following meters are part of most modern radio transmitters:

Direct-current voltmeter.	Alternating-current voltmeter.
Direct-current ammeter.	Alternating-current ammeter.
Wattmeter.	Frequency meter.
Ampere-hour meter.	Radio frequency ammeter.

The direct-current voltmeter gives the voltage of the supply mains which furnish the source of power for the motor generator and for charging the batteries.

The direct-current ammeter gives the ampere readings on the same circuit.

The wattmeter gives the reading of the amount of power on which the set is being operated.

The alternating-current voltmeter and ammeter give readings of conditions in the circuit extending from the alternator armature to the primary of the power transformer. By means of these meters the operator is able to tell whether or not the generator is generating properly.

The frequency meter reads directly the frequency of the alternating current generated by the alternator.

The ampere-hour meter has to do with the storage battery equipment, described fully in the chapter on the Charging Panel.

The radio frequency meter gives the value of the current flowing in the aerial circuit. It is also used for indicating resonance between two oscillatory circuits and may, therefore, be used for resonating the open oscillatory circuit of a transmitting system with the closed oscillatory circuit. Radiation indication, however, does not necessarily tell if the antenna is radiating properly.

This is due to the possibility of signal energy dissipation in nearby obstructions and surroundings, such as steel masts, guy wires, halyards and various other metallic bodies in which a considerable amount of energy might be lost in the form of absorption.

Key.—The transmitting key is operated by the hand of the operator in forming the characters of the telegraph code. The radio key is in principle exactly the same as the familiar telegraph key used in Morse telegraphy, but is slightly heavier in construction and is fitted with much heavier contacts as it handles, in most cases, directly, the full power of the transmitting set. If the set is operating on 2 kw. the full 2 kw. must flow through the key. For powers larger than 2 kw. a relay key is used which is nothing more than a remote-controlled electromagnet to which is fitted a movable arm fitted with heavy contacts to handle the heavy current used. The contacts of the radio key are usually made of platinum or sterling silver. These metals do not weld together as easily as other metals do when they are subjected to great heat.

High-potential Condensers.—As was explained before, the power transformer steps up the alternating current generated by the alternator and charges the condenser. A condenser may require anywhere from 10,000 to 25,000 volts for charging, depending on the design of the transmitter as a whole, which, of course, controls the size of the condenser.

At this point the student should go back and read over "Electrostatic Capacity," in which section a theoretical explanation of the function of the condenser is given. It is especially important that the way in which a condenser takes on a charge and discharges be understood.

Fig. 91.—The Dubilier condenser, transmitting.

A much-used and modern type of condenser is shown in Fig. 91. This, and the Leyden-jar type, are the only ones with which the radio operator of today comes in contact. The Leyden jar, illustrated in Fig. 92, is nothing more nor less than a huge jar made of special flint glass and coated on both the inside and outside, including the bottom, with an electrolytic deposit of copper. This deposit covers the entire surface mentioned to within about 4 in. of the top in the standard-sized jar. The standard-sized Leyden jar has a capacity of 0.002 mf. and the mica condenser shown here is of this size, although, the latter type is also made in the 0.004-mf. size for high-powered equipments. The ordinary size is 0.002 mf. in both types.

The mica condenser is described by the manufacturer of this type of condenser (Fig. 91) as follows:

A mica condenser is composed of several sections or units enclosed in a common casing of aluminum. Each of these sections or units comprises alternating sheets of mica and foil, over a thousand in number. The sections or units thus constituted are piled on top of one another in the aluminum casing, and each section or unit is separated from the next by a sheet of mica. The sheets of mica are larger than the sheets of foil so as to avoid any brush discharge at the edges.

Air, moisture, and small vacuum pockets must be eliminated from each section or unit. Hence an insulating adhesive of special composition, having the required dielectric properties, is forced through the entire condenser. The moisture and air are expelled, and the vacuum pockets are filled with this adhesive, which is deposited in a thin layer on each of the thousands of sheets of mica. Next, a melted-wax compound is poured into the aluminum casing, so as to fill any empty spaces between the condenser sections or units and the aluminum case.

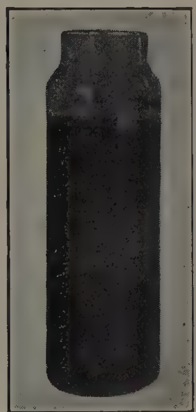


Fig. 92.—Leyden jar.

Before the wax has hardened, a pressure plate is placed on the topmost section or unit. After the cover is screwed on, this plate presses all the sections together. Because they are pressed together the sections cannot move about. It is highly important that the spacing between the metal foil and the mica be kept constant. This is done by the use of the pressure plate. A post passes up through the cover of the aluminum case and serves as one terminal, the aluminum case serving as the other.

Condensers used on transmitting sets are classed as high-potential condensers, the types used on receiving sets are classified as low-potential condensers. This classification comes from the voltage values handled by each.

If the condenser is punctured it is quite likely that only one unit of the bank has been damaged. If the Leyden-jar types are used it will be a very easy matter to locate the trouble as a dull, burning glow will appear around the hole as the key is pressed. It is rare to have the mica type puncture so that it can not repair itself. These condensers are self-healing, as explained in the discussion of protective condensers which are of the mica type. If, however, a unit does puncture it can be replaced with a spare which should always be a part of the regular station equipment.

The short wave condenser is another type of high-potential apparatus and will be discussed in connection with the open oscillating circuit. This latter condenser may be either of the Leyden-jar or mica type.

Other types of high-potential condensers which are not discussed in this book because of their obsolescence are: the compressed air type and the glass-plate tinfoil type. Neither of these are used in modern installations.

Energy in a Condenser.—The energy or amount of charge of a single condenser or of a bank of condensers made up of several units is found to be directly proportional to the applied voltage, and is expressed:

$$Q = CE$$

where

Q is the amount of charge.
C is the capacity.
E is the applied voltage.

In practical work, an understanding of the above is important so that the effect of a change of condenser capacity has on the set as a whole may be known. The way of connecting condensers on a commercial transmitting set should be considered here. It has been stated heretofore that a capacity of 0.016 mf. is required for a certain type of 2-kw. transmitter and that this capacity is obtained by connecting eight standard 0.002 mf. condenser units in parallel. There is, however, another method of connecting condensers in transmitting systems known as a series-parallel connection. With this method more condensers must be used but the total voltage strain is distributed by the series connection and the capacity maintained by the parallel connection.

Suppose one of the units is punctured; it is necessary to remove it if no spare is available. The removal reduces the capacity of the bank, by the formula for condensers in parallel. By the formula given above, the energy which may be impressed is reduced, which, in the case of the transmitter, would reduce the power of the set. By the wave-length formula previously given under Frequency and Wave Length, the wave length is affected by a change in capacity. It is, however, possible to compensate for the reduction in capacity by increasing inductance and in this way keep the original wave.

Coupling of Circuits.—Before taking up the spark gap, which would follow logically after the discussion on condensers, it is necessary that the action of coupled circuits be understood. The reason for this will become obvious as these circuits are discussed.

The discussion in this section will bring out the relationship between the closed oscillating circuit (condenser spark gap and primary of oscillation transformer, Fig. 87) and the open oscillating circuit (aerial, secondary of the oscillation transformer, and the ground). It will show the electrical reaction between these circuits and how the characteristics of one effects the characteristics of the other. On page 133, under Frequency and Wave Length it was demonstrated that a change in either the capacity or inductance of either circuit affected its wave length;

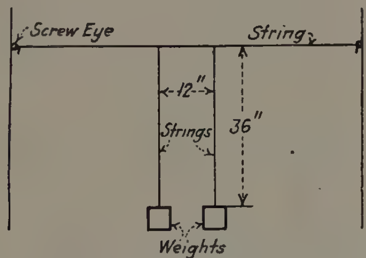


FIG. 93.—Mechanical analogy of coupled circuits.

an increase or decrease in the value of either one causes directly an increase or decrease in the wave length of the circuit.

The student is urged to perform the following experiment which can be easily made with materials available to every student and without expense, so that a proper conception of the action and reaction between coupled oscillation circuits and the effects of tuning and coupling on the rate of transfer of energy between such circuits may be had.

Experiment.—Fasten a piece of stout cord to two points about 6 to 8 ft. apart and each point about 6 ft. above the floor. Suspend from the central portion of this, about 1 ft. apart, two other cords about 3 ft. long, with two equal weights, say of ½ lb., at their ends. This need not be exact, but equal weights will make the demonstration easier (see Fig. 93).

Set one of the weights to swinging like a pendulum and note the effect on the other suspended weight. It will begin to swing and

the first pendulum started will quickly come to rest; all the energy will have been transferred to the second pendulum, which will attain an amplitude or length of swing almost as great as that given to the first pendulum in starting it.

If the experiment is allowed to proceed it will be noted that the first pendulum will again begin to swing or oscillate and the second pendulum will decrease in amplitude of swing as the first increases in amplitude, until all the energy is retransferred back to the first pendulum and the second pendulum will come to a state of rest. This transference and retransference of energy will continue until all the original energy is used up in overcoming the friction of suspension points and of the weights against the air and will last for a long time.

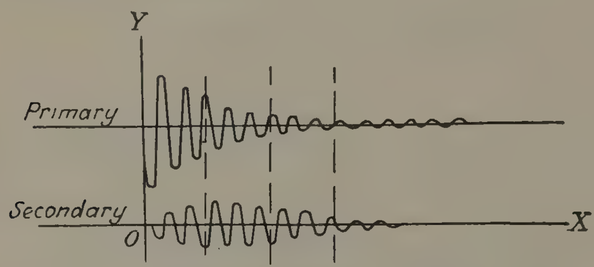


Fig. 94.—Comparative damping of coupled circuits.

Hence, if two pendulums having the same length are set in motion they will have the same time or period of swing, or, it may be said, they are in tune (resonance). Now change the length of the cord of one pendulum so that it is out of tune with the other and repeat the experiment and note the new result. The transfer of energy will be slow and incomplete as the second pendulum will begin to return the energy before all of it has been transferred by the first pendulum. This is the action of two circuits out of tune. Variation in the length of one of the pendulums will give various interesting results.

The pendulums correspond to the oscillation circuit, the weights correspond to the inductance, and the length of the cord to the capacity. The coupling is represented by the horizontal string from which the pendulums are suspended. The degree of closeness of coupling is represented by the distance between the

suspension points of the pendulum on the horizontal string and this should be varied and the results noted.

If this experiment is tried it will be seen that the time period of the pendulum is entirely dependent upon the length of the cord and not upon the weight attached. The inertia of the pendulum, however, is to some extent affected by the weights. This accounts for the apparent influence of the weight on the period.

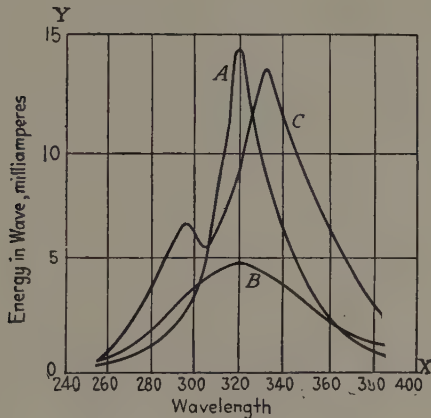


Fig. 95.—Resonance curves.

The experiment performed, the student has had an excellent mechanical analogy of what takes place when energy is transferred from the closed to the open oscillating circuits. If the swings of the pendulums were traced they would appear as in Fig. 94 which are in fact tracings of actual oscillograms of the currents in two circuits, coupled as in Fig. 87. When comparing current values, comparison should be made at points in both curves which are parallel to the ordinate—the dotted lines are parallel to the ordinate. It will be noted that the primary circuit is set into oscillation; this is the top curve and corresponds to the pendulum which was first started swinging in the experiment, after which the secondary is set into oscillation; the secondary would correspond to the second pendulum. The coupling of the circuits

represented by these curves is too close; the damping is high and, therefore, it would not be ideal as a radio transmitter.

Resonance Curves.—Resonance curves, shown in Fig. 95, graphically illustrate the characteristics of a radio transmitter. Assume that both circuits are tuned to 320 m. The energy in the waves is plotted as ordinates and the wave length as abscissæ. To make these measurements, the open circuit or secondary of the oscillation transformer is drawn as far away as possible from the closed circuit or primary in order that the reaction between the circuits might be at a minimum. Bear in mind that the wave length of the circuit is not changed throughout the entire series of readings, but that the effect on nearby wave lengths, when this given wave length is radiated, is measured and plotted in curve form. Curve *A* shows the distribution of energy in the closed circuit. In this case the energy is in the vicinity of 15 milliamperes at very nearly 320 m. The wave is rather sharply defined, very little energy being radiated at any other wave length.

Curve *B* shows the current distribution in the open circuit.

Curve *C* shows the resultant wave after the circuits have been coupled into their natural working position. This curve has two humps, which shows energy of marked proportion in two widely separate wave lengths, namely 295 and 333.

Pure Wave.—The law says:

> At all stations if the sending apparatus is of such character that the energy is radiated in two or more wave-lengths, more or less sharply defined, as indicated by a sensitive wave meter, the energy in no one of the lesser waves shall exceed ten percentum of that in the greatest.

Examine now the wave of the transmitter for which the resonance curves in Fig. 95 were taken. The energy of the radiated wave *C* is preeminent in two humps. The energy in the greatest wave, which is about 333 m., measures approximately 14 milliamperes. According to the law, as it reads above, the energy in the lesser wave should not exceed 10 per cent of that in the greatest wave, and 10 per cent of 14 milliamperes is 1.4 milliamperes. An examination of the curve will show that the energy in the lower hump is approximately 7.5 milliamperes, which is much over the limit prescribed therefore, this transmitter does not comply with the law. The energy in the lesser

wave might be reduced by changing the coupling or it may be impossible to make the transmitter emit a pure wave because of its design, particularly the design of the spark gap.

Percentage of Coupling.—If all of the lines of force from the primary could be made to link with the secondary the percentage of coupling would be 100. This, however, is an impossibility and something not desired as well. Commercial installations in most cases have a percentage of coupling varying between 15 and 20. A regulation of the International Wireless Convention provides that no commercial station shall have a closer coupling than 15 per cent.

Percentage of coupling is found by dividing the difference between the two humps by the intended wave. As an example, in the case of Fig. 96, the percentage of coupling is found as follows:

$$K = \frac{\lambda_1 - \lambda_2}{\lambda_3} = \frac{333 - 295}{320} = \frac{38}{320} = 11.9 \text{ per cent.}$$

K = percentage or coefficient of coupling.

This is rather loose coupling. If the coupling is loosened the two humps in the curve C would be farther apart and the energy would be more likely to concentrate in the larger or main hump. A transmitter complying with the law would have a resonance curve something of the shape of Fig. 96 in which the energy in the lesser wave is not more than 10 per cent of that in the greater.

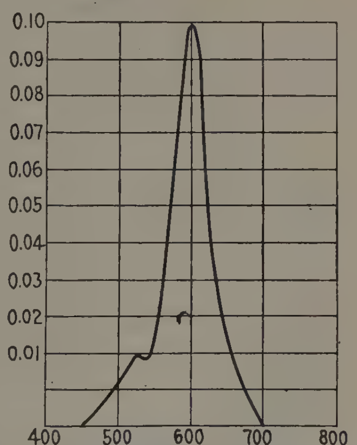


Fig. 96.—Resonance curve showing energy in two waves.

A resonance curve shows in a general way the distribution of energy in a radio transmitting system and allows an approximate calculation of the amount of interference to be expected from a given transmitter.

Properly plotted resonance curves allow the logarithmic decrement of damping to be calculated. They also show whether or

not the radiated wave is pure and in compliance with the U. S. Radio Regulations.

Questions

1. Draw a diagram of a condenser and spark gap.
2. Describe the nature of a condenser discharge through a spark gap and inductance.
3. What is the speed of radio waves?
4. What is the difference between undamped and damped waves?
5. Define a highly damped wave.
6. What is the relation between frequency and wave length?
7. Define close coupling.
8. Draw a diagram of a simple transmitting circuit.
9. What is a pure wave?
10. Plot a resonance curve illustrating a pure wave

CHAPTER XIV

SPARK GAPS

Spark Gaps.—The function of the spark gap is to provide a low-resistance path for the discharge of the condenser: this path is automatically broken once the condenser has discharged and so remains until the condenser has again been charged and is ready for discharge. Spark gaps are divided into three classes as follows:

1. Open gap.
2. Rotating gap:
   a. Synchronous.
   b. Non-synchronous.
3. Quenched gap:
   a. Self-cooled.
   b. Fan-cooled.

The various types of spark gaps are shown in Fig. 97*a*, *b* and *c*. The open gap is nearly obsolete and when used it is found only on small sets. Some open gaps are equipped with blowfans, which direct an air blast directly between the electrodes and prevent the gap from being short-circuited by the ionized air which forms immediately after the spark has discharged and which, if not blown away, would prevent the gap from properly functioning.

Refer again to Fig. 87 where the gap is connected across the condenser but in series with the primary of oscillation transformer and completes the closed oscillating circuit. Let us now assume that the key is pressed: the first thing that happens is that the condenser is charged. The condenser will continue to absorb the charge until the voltage at which the spark will rupture the gap is reached. The voltage at which this happens will depend absolutely upon the distance between the spark gap electrodes, and this is true regardless of the type of spark gap used. The voltage necessary to discharge across a given distance will, however, vary according to the type of gap used. To illustrate this point: 5,000 volts will discharge over a much greater distance if the discharge takes place between needle points, than if it takes place between two blunt points as those of the open gap illustrated in Fig. 97*a*.

When the discharge voltage of the spark gap is reached, the condenser discharges, as explained on page 127, under Oscillating Condenser Discharge, and sets the closed circuit in oscillation. Now a circuit can oscillate only so long as it is a closed circuit and as soon as the spark gap offers too high a resistance for the passage of the high-frequency, high-voltage, electric current in the form of a spark across the gap, the spark ceases and the circuit is opened, resulting in a stopping of the oscillations in this circuit. It is desirable that the duration of the oscillations in the closed oscillating circuit be as brief as possible in order that the open oscillating circuit may be free to oscillate at its own natural period.

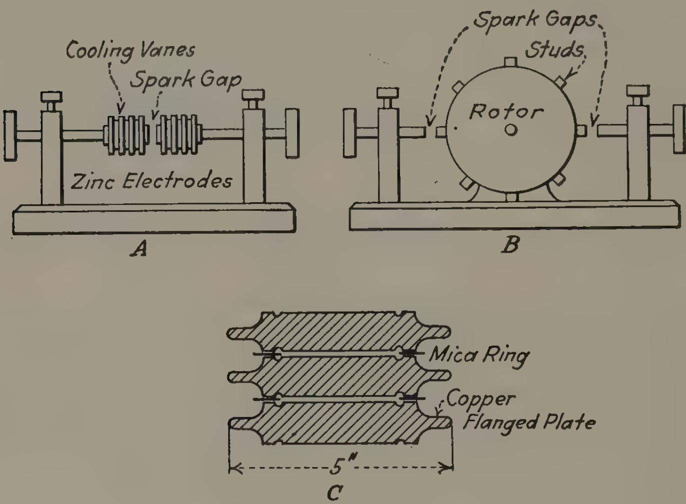


Fig. 97.—Types of spark gaps.

Reaction between the Oscillating Circuits.—Oscillations in one circuit cause oscillations in another circuit if they are coupled. The oscillations first set up by the discharge of the condenser induce oscillations in the open circuit from the closed circuit. If the second circuit is not complete, however, it is in reality not a circuit and no oscillations could be induced in it. To illustrate this point, suppose there is a break in the aerial connection. The aerial then is not connected to the secondary of the oscil-

lation transformer and there is no open oscillating circuit. Remember, that the open oscillating circuit consists of the aerial, secondary of the oscillation transformer, and the ground, and that if any of these is left out it is no longer the open oscillating circuit. The statement, therefore, to the effect that if the aerial is disconnected by the break in the aerial connection it is no longer an open oscillating circuit, is correct. Therefore, no oscillations can be induced in the open circuit by the closed circuit unless the open circuit is complete. Even though a spark gap is inserted in the closed primary circuit, the student should

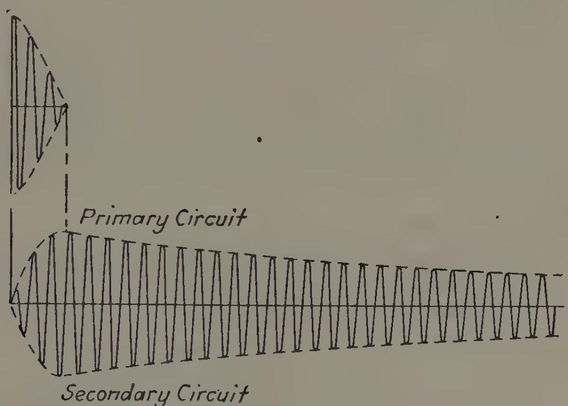


FIG. 98.—Damped oscillations with a quenched gap.

learn to think of the closed circuit as uncut, since the gap becomes a conductor when the spark is passing.

After the open oscillatory circuit has been set into oscillation by the closed circuit, it immediately has a reflexing effect on the primary circuit. The primary circuit then is set into oscillation a second time, by the induction effect from the secondary. There is mutual induction between the two circuits. This transfer and retransfer of energy has the effect of setting up a number of different frequency oscillations and the resultant wave is not sharp; it is broad, so to speak, and its energy is spread over a wide band of wave lengths.

The broad wave is undersirable because it produces considerable interference at the receiving station.

Now the question naturally arises, How can this reaction between the circuits resulting in the broad wave be eliminated? The answer is, By quickly damping out or stopping the oscillations in the primary circuit—in fact, by opening this circuit. How can this be accomplished? By the use of a spark gap that regains a high resistance after the first few oscillations have taken place. When such are the characteristics of the spark gap, it not only stops the oscillations after the first few have taken place but in so doing it opens the primary circuit and there can be no retransfer of energy from the secondary with its resultant effect of a broad wave.

All of the gaps illustrated in the Fig. 97, with the exception of the open gap, function well in damping out the oscillations in the closed circuit, allowing the open circuit to oscillate in its own natural period. These gaps "quench" the oscillations in the primary, resulting in oscillations as shown in Fig. 98. In this figure, notice the very few oscillations necessary to set the secondary circuit into oscillation.

The amount of current discharging across the spark gap is an indicator of the power of the set as a whole. If the spark gap is lengthened and the power sent into the transformer increased, the power of the set as a whole has been increased. It should not be understood, however, that the longer the spark gap the more power radiated, because there is a point at which the spark gap works most efficiently, and if the spark gap is lengthened beyond this point, the radiation goes down instead of up. It is logical from the above, that the power of the set is decreased by shortening the spark gap. This is one of the things that must be done when the set is being adjusted for low-power work. When working on low power the charging voltage of the condenser is low, obviously, and the spark gap must be shorter than when it is high.

Due to the high impedance of the secondary of the power transformer, the condenser discharges across the spark gap through the primary turns on the oscillation transformer.

When the spark is discharging across the gap the condenser is practically short-circuited, and, were it not for the fact that the gap is soon restored, the condenser could not take on another charge. If the spark gap electrodes become short-circuited in

some way, the effect would be the same; no charge could be impressed on the condenser.

Spark Frequency.—Perhaps the proper title to this paragraph should be "group" frequency, for each spark sends out a group of oscillations. The frequency of the alternating current sent into the primary of the power transformer is the controlling factor of the group frequency. Figure 99 shows just what takes place while the alternating current is flowing. It shows the frequency relationship between the alternating-current of the generator and the spark discharge. Study this curve. Notice that the current from the generator starts off in the regular way. It commences to rise and does so until the point *GV*, (gap

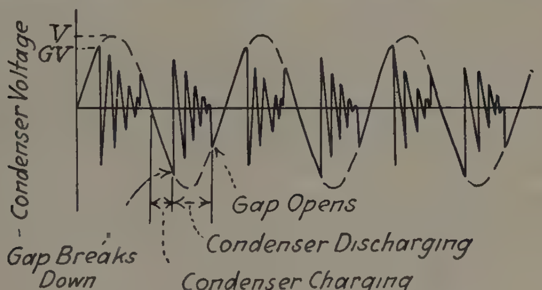


FIG. 99.—Character of a spark discharge.

voltage) is reached. At this point the current is high enough to ionize the spark gap. The condenser then discharges and the damped oscillations are produced; these are labeled, "condenser discharging" in the diagram. The condenser discharges just so long as it has the strength to do so, until the charge it has accumulated has been dissipated across the spark gap in the form of a spark discharge. The gap then opens and the condenser begins to take on another charge. This continues as long as the alternating-current flows into the power transformer which in turn charges the condenser. It will be seen by referring to the diagram that a spark discharge takes place for every alternation: the exact instant and point on the alternating-current sine curve at which this discharge takes place depends entirely upon the discharge voltage value to which the spark gap is set. Briefly, the spark-train frequency is dependent upon the alternator

frequency and on the spark-gap adjustment. Usually, this adjustment is made so as to give one discharge for every alternation (half cycle) of the alternator. In a standard 500-cycle transmitter, therefore, there would be 1,000 discharges per second. As sound depends upon frequency of vibration, this spark frequency gives a high, musical note which is pleasing to the ear. If the spark-train frequency is low the resultant note is of a low and rasping sound.

Straight Spark Gap. Open Gap.—This type of spark gap is shown in the Fig. 97*a* and consists of two electrodes made of zinc or other similar metal. The distance between the electrodes is adjusted to the position desired. This type of gap gets hot very quickly and, as was explained before, is, therefore, sometimes fitted with a blower motor which prevents, to some extent, arcing and complete short-circuiting of the gap by the hot gases. The straight or open gap is used only on small sets because of the difficulty of cooling. There is a great magnetic reaction also between the primary and the secondary circuits when using this gap, which results in a very broad wave which is difficult to tune out at the receiving station. Some of these gaps have cooling flanges to aid in dissipating the heat. The other types of spark gaps shown in the figure are rapidly replacing the open gap; in fact they have nearly done so and few open gaps are now in use. With an open gap the oscillations would appear somewhat like Fig. 94; the oscillations in the primary circuit are not rapidly damped out, a disadvantage which has been described in detail under Reaction between the Oscillating Circuits in this chapter.

Rotating Gap (Synchronous).—This type of gap is shown in the Fig. 97*b* and in most equipments is fitted to the end of the generator shaft. The idea of the gap is that it shall (1) provide a path for the spark at predetermined periods in synchronism with the alternator frequency, and (2) that it shall quickly quench out the oscillations in the primary circuit, thus allowing the secondary circuit to oscillate in its own natural period. It does both of these things almost perfectly.

In considering the first function, providing a path at predetermined periods, refer to Fig. 94 in which is shown the long-drawn-out oscillations of the primary circuit. It is easily seen that if the oscillations could be stopped in the primary circuit

after the first three cycles of discharge (about where the dotted lines cross the curve) the secondary could then freely oscillate at its own natural period and the radiated wave would be of one frequency only—sharp and easy to tune out if necessary. This can be done by using the synchronous gap. The rotating element of the synchronous gap has evenly spaced electrodes which are so fixed in relation to the field coils of the generator that as soon as the condenser has been charged up to a given point, say, point GV in Fig. 99, the rotating stud has passed the stationary electrode and the gap is opened. By the time the next electrode comes opposite the stationary electrode and the point A has been reached, the gap is again formed and the discharge takes place. As this happens in a most regular way and is adjustable, that is, the point at which the gap is to open may be fixed at will, the note is very even and musical in character. The second function is taken care of automatically, for when the gap opens, it breaks the primary circuit and it is no longer a circuit, therefore, there can be no reaction from the secondary circuit and no conflicting of different spark-train frequencies with a resultant broad wave.

There are as many electrodes on the steel rotating disc as there are alternator field poles. As an example, suppose the alternator has 24 field poles; the rotating disc then has the same number of studs. There would be 24 breakdowns of the condenser every revolution, resulting in 1,000 sparks per second if the standard 500-cycle generator is used. This may be proved by the frequency, formula

$$f = \frac{n \times s}{2} = f = \frac{24 \times 41.66}{2} = \frac{1{,}000}{2} \text{ (approximate)} = 500$$

cycles or 1,000 alternations.

where f = frequency
n = no. poles
s = speed per second

A reference to the curve (Fig. 99) shows that there are two discharges of the condenser per cycle or one per alternation.

Arcing is absolutely prevented in the synchronous gap because of its rotation. This form of gap can handle any amount of current. The largest spark station in the world, 100kw. at Arlington, Va., employed this type of gap at one time.

On installations where the motor generator is not located near the radio set proper, as on ships, the generator is sometimes placed in the engine room and the rotating disc with studs is mounted on a synchronous type of motor which is installed as a separate unit near the radio panel in the radio room. As this motor runs in synchronism with the generator, the same effect is produced as when the disc is mounted on the generator shaft.

Rotating Gap (Non-synchronous).—The non-synchronous rotary gap consists of a rotor on which are placed many studs which rotate between stationary electrodes. It is similar to the synchronous type, except that it is mounted on a small motor, entirely separate from the motor generator. The motor does not rotate in synchronism to the generator frequency, nor are the studs on the gap limited by the number of field coils in the generator, as with the synchronous gap. Figure 97*b*, while it served the purpose of illustrating the synchronous gap, may also be used to explain the non-synchronous gap.

The important difference between the two types is that one rotates in synchronism with the generator frequency and the other rotates independent of the alternating-current frequency. In most cases the synchronous gap is mounted on the end of the generator shaft, while the non-synchronous gap is separated entirely.

The note produced, therefore, is of a high pitch but may consist of several notes merged into one, giving a note similar to that of a harmonica rather than the clear flute-like note produced by the synchronous gap. The non-synchronous gap is used mostly on 60-cycle sets in place of the open gap. When so used, it gives a much more pleasing note than could be had by using the open gap. Because it is rotating, it keeps cool and the range of the station as a whole is materially increased. The non-synchronous gap may give as high as 1,000 spark trains per second: this accounts for its high pitch.

Quenched Gap.—It has been shown that it is desirable to have a spark gap which cools quickly, thus extinguishing the primary oscillations and allowing the secondary to oscillate in its own natural period. This may be accomplished to a great extent with the quenched type of spark gap which consists of a number of plates turned out to the special shape shown in Fig. 97*c*. The

entire gap may consist of from ten to sixteen plates arranged in a rack. The plates are insulated one from another by mica or other insulating material washers. A groove is turned in the plate just inside of the insulating gasket which prevents the spark from leaving the sparking surface of the plate and burning the washers which separate and insulate the plates one from another. These washers are called gaskets. The sparking surfaces in some quenched gaps are of silver, but for cheapness of construction a hard, bronze-like metal has served in a satisfactory way. In order that there shall be a tendency for the spark to stay in towards the center, the part of the plate which is the sparking surface is slightly thicker than that part on which the gasket rests. When the plates are placed side by side, the space between the sparking surfaces is less than the space occupied by the thickness of the gasket. Electricity always takes the easiest path, therefore, the spark jumps on the surface which is in towards the center of the plate.

The oscillations in the primary and the secondary circuits when using the quenched gap would be as in Fig. 98, even when using close coupling, a condition which is obtained when using the rotary gap only with loose coupling and one which is almost impossible to obtain when using the straight open gap. It is well to note here that the action of the quenched gap is exactly opposite that of the plain gap. The quenched gap tends to stop the primary oscillations very quickly after the secondary circuit is in full activity. The plain gap tends to keep up the primary oscillations as long as it is possible, giving energy to the secondary oscillations as fast as it is radiated.

The length of the quenched spark gap depends upon the number of plates connected in the circuit. These are made adjustable by making contact on one side with an adjustable lead with a clip on its end. Most types of quenched gaps are provided with blowers, especially if the power is over 2kw. There is, however, a type used on shipboard which does not require a blower. The individual plates each are a separate unit with great heat radiating surface.

The separation between the plates is very small, somewhat less than 0.01 in. Each spark is therefore small and does not produce much heat. It is the practice to allow 1,200 volts per gap.

The quenched spark gap may be used on all powers up to 35*kw.* It is comparatively noiseless in operation, has no moving parts, requires but low voltage, give synchronous spark discharges when properly adjusted, and gives high radiation in the aerial circuit because of the close coupling possible. Most important is the pure wave which is radiated by the quenched gap set due to the low logarithmic decrement (damping) of the oscillations in the open circuit.

The range of any station may be materially increased in many instances by the use of a quenched gap. This follows logically with the close coupling which may be employed.

The care required by the quenched gap is simply the cleaning of the sparking surfaces of the plates when the note commences to get raspy. In some installations which are continuously used, this is necessary every two weeks, while on shipboard, where the apparatus is not used so continuously, the cleaning may be necessary but once a month or even less often.

Questions

1. Name four types of spark gaps.
2. What is the function of the spark gap?
3. What would happen if the gap electrodes should fall together or become short-circuited?
4. What takes place between the spark electrodes just prior to the condenser discharge?
5. Describe in detail the construction of the quenched gap.
6. Draw a graph of the oscillatory discharge of a condenser in a circuit employing a quenched gap.
7. Why does rapid quenching in the closed oscillatory circuit produce a wave of low decrement in the open radiating circuit?
8. What is meant by spark or group frequency?

CHAPTER XV

ANTENNA AND GROUND

Referring back to the explanation of Propagation of Waves it will be remembered that the antenna and the ground act like two plates of a huge condenser and the electrons fly off into space as they are passing from one plate (antenna) to the other plate (ground). The antenna and ground constitute the capacity of the open oscillating circuit and because this capacity is distributed and not concentrated as in the closed circuit the open circuit is a good radiator of ether waves.

The antenna, simply speaking, is a device for increasing the range of transmission and reception of electromagnetic waves.

There are two general classes of antenna: those that act primarily as electrical condensers, and those that act primarily as electrical inductances. The first is the most commonly used type and is simply known as an "antenna." The second type is known as the "loop antenna," "coil antenna," or when used for that particular purpose, "direction finder."

Forms of Antennae.—There are various ways of constructing the antenna and these forms are commonly classed as follows:

1. Inverted L.
2. T.
3. Umbrella.
4. Cage or hoop.
5. Loop.

The vertical wire first used by Marconi is obsolete and will not be discussed. It consisted simply of a single wire from 50 to 100 ft. long erected in a vertical position. The vertical antenna of one wire is perhaps the best radiator of electromagnetic waves but the difficulty of erecting a wire of sufficient inductance value in a vertical position has made it more or less obsolete.

The *inverted-L* type antenna is the most commonly used type today. This type is easily erected and is found on most of the

smaller merchant vessels. It is similar in appearance to the *T* type antenna, the only difference being that the lead-in, or rattail, is taken from one end, *A*. The advantages of this type of antenna are similar to those of the *T* type, viz: ease of erection, structural strength, low cost of construction as compared with certain other types. It has been found that when using the inverted-L type antenna, a directional effect is noticeable if the horizontal portion greatly exceeds the vertical portion. This effect has been taken advantage of in some of the large trans-Atlantic stations.

The *T* type antenna is used mostly on shipboard, where the length of the antenna prevents the lead-in from being taken off at

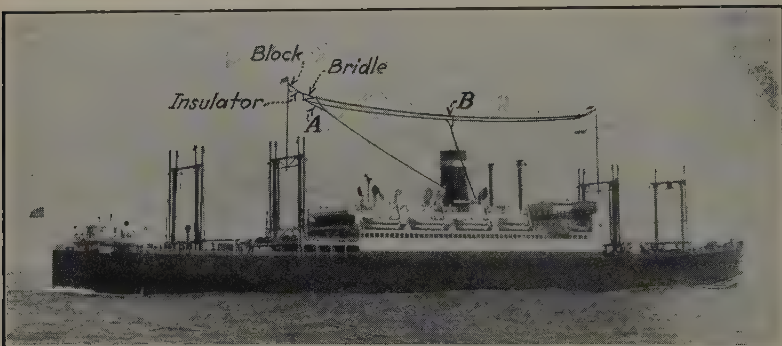


FIG. 100.—*T* or *L* type antenna.

one end. An antenna of this type is easily erected, and is usually made to stand great stress. Fig. 100 point *B* shows where the lead-in is taken off in this type. Given a flat top space, as in Fig. 100, if the lead is taken off from the center the natural wave of the entire antenna is slightly reduced. This is due to a decrease in the inductance in the flat top portion because of a neutralization effect when the antenna current in both halves flows towards the center.

The *umbrella* type of antenna is used mostly at the larger shore stations, and also for portable sets such as those used by the Army and Navy in the field service. This antenna is called an "umbrella" antenna, because it is formed very much like an umbrella. The principal advantage of this type of antenna is that only one mast is necessary, which reduces the total cost of

erection. When used on smaller portable field sets, it is easily and quickly erected and is, therefore, most suitable for this service (Fig. 101 for construction of this type).

A type of antenna used more on war ships than on merchant vessels is the *hoop* or *cage*, type. This type of antenna is constructed along the lines of the inverted L or T types and the lead-in may be taken off in the same way. Instead of using straight spreaders, however, a hoop is used around which the wires are equally spaced.

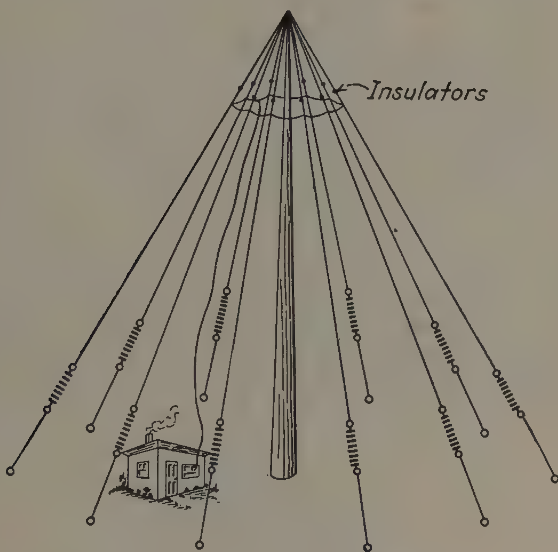


FIG. 101.—Umbrella antenna.

The *loop* antenna is shown in Fig. 102. This type may be used if two or more stages of radio amplification are provided in the receiving set. The loop is not used with transmitting sets. The loop has a very pronounced directional effect and will be explained in detail in connection with the radio compass, the only place it is commonly used in commercial practice.

Insulation.—The insulation of the antenna should receive the most careful attention. Figure 103*a* shows in detail how the insulators are fastened to the spreaders in the flat-top type of antenna. The voltage in the antenna, when the transmitter is

in operation, is greatest at the end most remote from the ground and it is at this point where the heaviest insulation must be provided. It is the practice, however, to use the same number

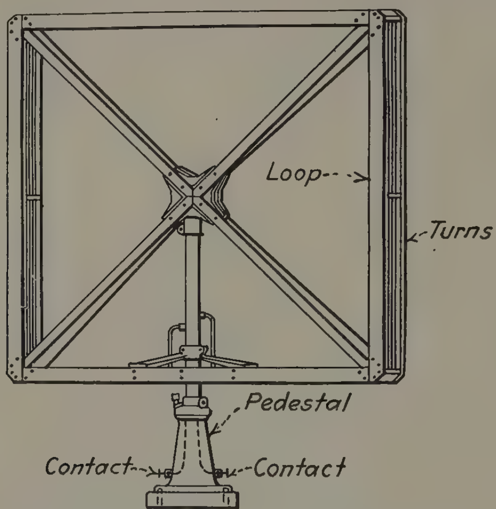


FIG. 102.—Loop antenna.

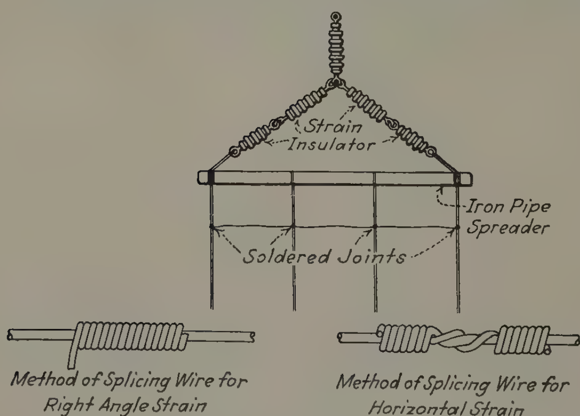


FIG. 103*a*.—Methods of splicing antenna wire.

of insulators on both ends of a ship antenna, although, in shore stations, especially, heavy insulation is provided at this point of high potential strain. It is obvious, of course, that if the

antenna is to be used only for receiving, a heavy insulation is not required.

It is most essential that the antenna wires be thoroughly insulated from the ground. The voltages imposed on antennae range from 10,000 to 50,000 volts and even more, so that the maintenance of proper insulation is difficult, as the high or radio-frequency currents in the antenna easily leak to the ground. When the antenna insulators become covered with dust or soot as on the ships, the insulation is greatly reduced and the antenna current and radiation decreases rapidly, as will be noted from the antenna ammeter reading.

Antenna Characteristics.—The characteristics of any type of antenna depends upon the value of the capacitance, inductance, and effective resistance. The capacity and inductance determine the length of the radiated waves, and the resistance determines the damping. In speaking of the first characteristic, it may be said that the capacitance of an antenna designed for an aeroplane or a small amateur station would be 0.0005 mf. The capacity of an ordinary ship antenna may be from 0.0007 to 0.0015 mf., and for a large land station 0.005 to 0.015 mf.

The energy which can be given to a condenser when it is charged to a certain voltage is computed by the following formula:

$$P = \frac{C \times E^2 \times N}{2}$$

where

E^2 = charging voltage, squared.
C = capacity.
N = number of charges per second.

To increase the supply of power to an antenna, it is necessary, therefore, to raise the voltage or increase the number of charges per second.

It is not practical to raise the charging voltage to greater than 50,000 volts without loss from brush discharges and leakage and the rate of charging should not be raised above 1,500 sparks per second. To increase power, therefore, it is necessary to increase

capacity, which is done by increasing the spread and number of antenna wires.

The higher an antenna is erected, the better radiator it is because of the larger dielectric between the antenna and ground, which results in a greater electrostatic field. The more concentrated a condenser, the smaller the dielectric separation between the plates, and it becomes a poorer radiator of electromagnetic waves.

The antenna is a part of the open oscillating circuit and, as such, has inductance, but not in large values, 50 to 100 microhenries being about the range.

The antenna offers more resistance to the high-frequency current than it would to direct current of the same value, due to the so-called "skin effect." The skin effect is the phenomenon produced by the non-uniform distribution of current throughout the cross-section of a linear conductor. It is caused by variations in the intensity of the magnetic field due to the current in the conductor. The effective resistance of an antenna varies from 2 to 4 ohms for a ship station and from 5 to 10 and sometimes as high as 20 ohms for land stations. It is computed by the formula:

$$R = \frac{P}{I^2}$$

where

R = resistance in ohms.
P = antenna power in watts.
I^2 = antenna current, squared.

Construction of Antenna.—There are several important things to consider before the actual work of erecting the antenna is commenced. All of these points affect very materially the workings of the antenna and the set as a whole. Because of the fact, that the antenna is more or less permanent once it is installed, and also because it may make the most efficient apparatus work poorly if improperly installed, it is necessary that it be carefully planned.

The antenna should be erected in as clear a space as can be found. Avoid all surrounding objects such as trees, high buildings, metal tanks, etc. High hills and mountains will also affect the transmission or reception of signals to and from points lying on their other side.

The length of the antenna is a very important consideration as it is upon this that its fundamental wave length depends. For ordinary commercial practice the antenna is seldom more than 300 ft. in length. If the antenna is too long, it may be broken into two sections by the insertion of insulators at any desired point, and only part of it be used.

It is a generally conceded fact that the higher the antenna the better the results obtainable. There is however, a limit to the height at which the most efficient results may be obtained due to the fact that the higher the antenna, the longer must be the lead-in or the ground connection.

The capacity of the antenna depends upon its height, the number of wires used, and their distance apart. The advantage of placing more than one wire in the antenna is that, with more wires stretched side by side, the effective resistance is decreased and the ratio of antenna capacity to inductance is increased, so long as the wires are kept quite well separated. A safe rule to follow in the spacing of the wires is to have them at least one-fiftieth of the length of the antenna apart. As an example, in an antenna 100 ft. long, the wires should be spaced at least 2 ft. apart.

Copper or phosphor-bronze, single-strand or multi-strand, wire should be used for antenna construction. Multistrand is the best where tensile strength is required, and this is the kind almost universally used in commercial installations.

The insulation of the antenna has been referred to before and should be carefully planned. Make sure that all lead-in wires are carefully insulated. All guy wires, supporting wires, and such should be broken up into small sections by strain insulators to prevent the absorption by them of any energy from the antenna. In small installations this is unnecessary. Antennae used for receiving purposes only do not require such careful insulation although they should be thoroughly insulated if good results are to be obtained.

All connections in the antenna and ground system should be soldered, for the reason that all metals corrode; and this corrosion, which appears in the form of verdigris, acts as a very poor conductor for the feeble radio waves coming into the receiving antenna. The best methods of making splices are either by using connectors especially made for this purpose, and which provide for the holding of the two ends of wire together by set screws, or by twisting the wires together as shown in Fig. 103*a* and then soldering to reduce the resistance in the antenna circuit.

Radiation Resistance.—The effective resistance of an antenna appears in various forms, such as heat in the wires, brush discharge, leakage of insulators, high frequency resistance and, finally, radiation resistance. All of these, with the exception of the last mentioned should be kept as low as possible. Radiation resistance is used as a measure of the ability of an antenna to radiate power. The higher the radiation resistance, therefore, the more power there is being radiated. Resistance, remember, represents a loss in energy and the more energy lost in the form of radiation the better the results.

Fundamental Wave Length.—By fundamental wave length of an antenna is meant, the wave length that is radiated or received by this antenna circuit alone if no inductance coil or condensers are inserted in series with it. Roughly speaking, the fundamental wave length of an antenna is four and one-half times its length. For instance, an antenna 200 ft. long with a lead-in 100 ft. long would have a wave length of four and one-half times 300, which is 1,350 ft. or 411.48 m. The inductance of an antenna will, of course, depend upon its length. If the antenna is shortened, the inductance value is lessened; and if the antenna is lengthened the inductance value is increased. The placing of a condenser in series with the antenna decreases the effective capacity of the antenna circuit. It is the same as if two condensers were put in series, as the resultant effect is less. If an antenna is found to have a natural period greater than that for which the station is designed, it is possible to bring the wave length down by the insertion of a short wave condenser. It is not practical to reduce the wave length of an antenna more than 50 per cent by the use of such a condenser.

In a receiving circuit, if a condenser is placed in series to an inductance which is connected in series with the antenna and ground, it is possible to vary more gradually the wave-length value of the circuit.

Emergency Antenna.—The antenna is primarily an elevated wire well insulated from the ground, therefore, in case the main antenna should be carried away in a storm, an emergency wire should be erected at once. In erecting this wire comply with the following rules as far as possible.

1. Erect as high as possible.
2. Keep clear of smokestacks, riggings, and other surrounding objects.
3. Insulate carefully, especially at the remote end.
4. Fasten securely.

Extra antenna wire should always be available for an emergency.

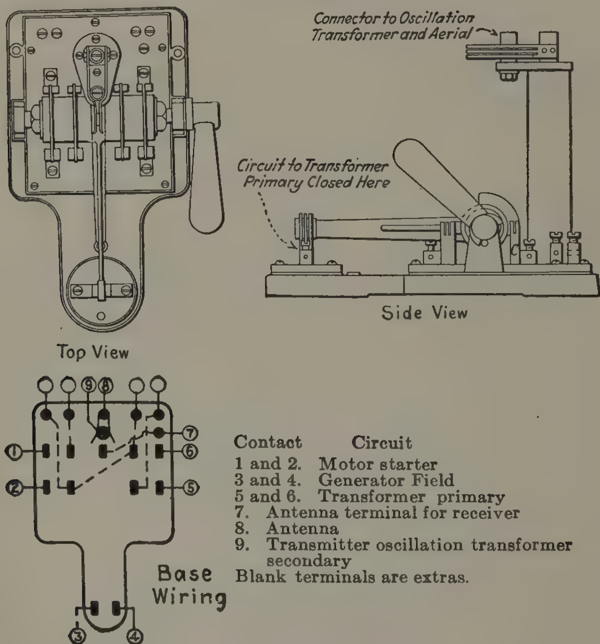
Ground.—The antenna is one side of the huge condenser of the open oscillating circuit, the ground is the other. On shipboard the ground connection is made to the steel hull, or, if it is a wooden vessel, a large copper plate several square yards in area is fastened to the hull below the water line and a connection made thereto.

On shore installations, the ground is made by connecting to the water-supply pipes, which are of metal and which make contact with the earth or, if these are not available, a network of wire screening or metal plates is buried in large quantities so that connection is made over a considerable area.

Counterpoise.—In places where the ground is rocky or sandy and has poor conductivity, it becomes difficult to make a good ground and in places like this a counterpoise is used. A counterpoise consists of an insulated wire or a network of wires stretching out over the ground as a mass of metal work in a radial form with the radio station as the center. The counterpoise should cover the area directly beneath the antenna wires and extend out about one-third further. For instance, if an antenna covered 2,000 sq. ft., the counterpoise should cover about 3,600 sq. ft. On aeroplanes the metal work of the engine is used as a counterpoise, in lieu of a ground.

Current and Voltage in the Antenna System.—This distribution of energy has been referred to before, but in the way of a

review, it may be summed up as follows: The greatest current in the open oscillating circuit (antenna and ground) is at the ground connection, and the highest voltage is at the end of the antenna which is the farthest from the ground connection. The best insulation therefore, must be at the point of highest voltage or pressure, which is in the antenna, as explained. The radiation meter is usually placed in the ground connection, for it is at this point there is most current to measure.



Contact	Circuit
1 and 2.	Motor starter
3 and 4.	Generator Field
5 and 6.	Transformer primary
7.	Antenna terminal for receiver
8.	Antenna
9.	Transmitter oscillation transformer secondary

Blank terminals are extras.

FIG. 103*b*.—Type I antenna change over switch.

In all but very high-powered stations, the same aerial and ground is used for both transmitting and receiving, the change being made by the antenna change-over switch.

Questions

1. What is the function of the antenna and ground system?
2. Name and describe the two types of antenna used on shipboard.
3. Why must the antenna resistance be kept as low as possible?
4. What is meant by the natural period of an antenna?
5. On shipboard where is the ground connection usually made?

CHAPTER XVI

PRINCIPLES AND OPERATION OF RADIO RECEIVING APPARATUS

Requirements for Receivers.—The fundamental basis for the receiving circuit is *resonance*. In considering the action of an antenna while it is receiving electromagnetic waves, it may be well to remember the principle of a conductor which is being cut by lines of force, and the electromotive force generated therein. Similarly, when an antenna is cut by the lines of force set up by the transmitting station, a current is set up in the antenna which is readily detected by the receiving set, and made audible in the headphones. The receiver must be in tune with the transmitter in order that the ether waves sent out by the open oscillating circuit of the transmitter may affect and set up corresponding currents in it. The subject of resonance has been referred to so many times before that it will suffice to say that the wave length or natural period of oscillation of the receiving circuit must be the same as that of the transmitting set, if signals are to be received. When the receiving circuit is of such characteristics that it will oscillate at the same natural frequency as the incoming waves, these waves, even though they are extremely feeble, will build up large oscillations in the receiving circuits. It is true, of course, that when using damped waves the wave lengths of neither the transmitter nor the receiver are sharply defined and, for this reason, exact adjustments are unnecessary. For example, a transmitter may be sending on a 600-m. wave length and the receiver may respond, even though it be tuned to within 40 or 50 m. of the transmitted wave. This effect is referred to as "broadness" in tuning. The degree of broadness depends entirely upon the design of the apparatus involved, and some damped-wave equipments are relatively sharply tuned. On the other hand, when undamped waves are used, the circuits are very sharply tuned, and a deviation of only 10 or 20 m. may

throw the circuits entirely out of tune. Both of these characteristics will become apparent as the discussions of the various types of sets are studied.

Receiving sets are divided into two general classes, namely, damped and undamped sets. Damped-wave sets can be used for the reception of spark stations or interrupted continuous wave transmitters. In this assignment only damped-wave receivers will be considered. Receivers for undamped waves use the vacuum tube. These will be covered in detail in a subsequent assignment after the theory and operation of the vacuum tube has been explained.

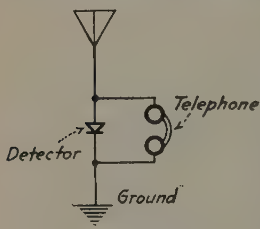


Fig. 104.—Simplest receiving circuit.

Simplest Receiver.—In spite of the fact that, ordinarily, the beginner believes that radio receiving apparatus is complicated, the circuit shown in Fig. 104 will receive damped-wave signals. Excepting the aerial and ground, but two pieces of apparatus are necessary, as shown by the diagram—a detector and a headphone. If the aerial happens to be of the proper natural wave length of the transmitting set, it is in tune with the radiated wave, and this wave will set up oscillations between the aerial and ground of the receiving set which are rectified by the detector and made audible by the headphones.

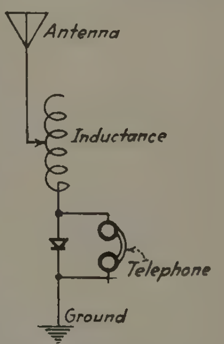


Fig. 105.—Simplest tuned receiving circuit.

To begin with an illustration, assume that a transmitter is sending on a 600-m. wave length. If the receiving circuit, as shown in Fig. 104, has a natural period of 600 m., signals will be heard in the headphones as explained above. The question now naturally arises, Why is this circuit not generally employed and why is additional apparatus used in commercial sets? The answer is simple. Suppose the transmitter mentioned above was transmitting on a 900-m. wave length, the circuit in Fig. 104, being responsive to 600 m. only would not oscillate and no signals would be heard. It is necessary to adjust the receiving circuit to resonance with the transmitter, *i.e.*, tune it to 900 m. This is done by the insertion

of an inductance coil in the circuit, as in Fig. 105. It will be remembered that the introduction of an inductance in an oscillating circuit increases the wave length of the circuit. The set may now be tuned to any wave length within the range of the coil.

Again, assume that the transmitter in the case was sending on 600 m. and the natural period or wave length of the set in Fig. 104 was 900 m., which is too long to receive from the station sending. In this case, if a condenser is placed in series with the aerial and ground, as in Fig. 106, the wave length of the circuit may be tuned down to 600 m. A condenser acts conversely to an inductance, reducing instead of increasing the wave length, provided it is in series with the circuit into which it is introduced.

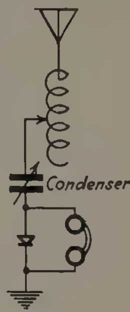


FIG. 106.—Tuned circuit with series condenser.

These three facts have been brought out:

1. A receiving circuit may be fixed in wave length adjustment.

2. A receiving circuit may be made adjustable by the use of an adjustable inductance, in which case it tunes higher than the natural period of the aerial alone.

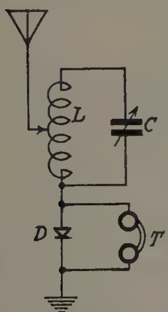


FIG. 107.—Tuned circuit with parallel condenser.

3. A receiving circuit may be made adjustable by the use of a variable condenser, in which case it will tune lower than the natural period of the aerial circuit alone.

It follows then, that, if the condenser is introduced in series with the aerial (Fig. 106) and provided with a short-circuiting switch the circuit may be tuned far above and almost 50 per cent below the natural period of the aerial circuit.

The only thing necessary in the operation of a simple receiver, as explained above, is the adjustment of the detector and the adjustment of the inductance coil in the aerial circuit. Theoretically, it might be said that it is only necessary to set the detector to a sensitive point and signals would be heard, provided, of course, that they are of the same wave length as the receiving circuit; but practically this would be the rare case and usually the simplest of receiving sets are provided with an

inductance coil. The objection to this circuit is that it is not selective and, as mentioned in the first paragraph in this chapter, will tune over a wide band of wave lengths. If a circuit on which a number of different stations, all transmitting on different wave lengths, could be heard simultaneously was desirable, this circuit would be excellent, in fact, an arrangement is made on modern commercial receivers for a *stand-by* circuit which is essentially a circuit of this kind. For general listening-in the operator switches to the stand-by circuit, and he is then able to hear a station calling him even though his set may not be exactly tuned to the transmitted wave. This is applicable to damped wave sets only.

Figure 107 is the same as Fig. 105, but modified by placing the variable condenser in shunt or in parallel with the inductance coil. In this position, it has the effect of increasing the capacity of the aerial and ground, for it is in parallel with them and condensers in parallel increase capacity. This results in an increased wave length of the circuit as a whole, and is an absolute converse of the condenser effect in Fig. 106 in which the effect is to decrease the wave length of the circuit as a whole.

The receiving circuit shown in Fig. 107 is very much like the closed oscillation circuits explained in previous assignments. Its action is similar also.

Detectors.—One of the most important pieces of equipment used in connection with the receiving set is the detector. Detectors used at the present time may be divided roughly into two general classes; namely, the crystal type and the vacuum-tube type. Again, the crystal type may be divided into two general headings; first, those that require an external electromotive force for their best operation; and, second, those that operate by themselves without a battery.

Crystal detectors requiring a battery for operation are carborundum, and zincite bornite, the latter being manufactured under the trade name "Perikon." Only the former is still in use.

Crystal detectors which operate without a battery and which have almost universally replaced the battery-operated type are galena, silicon, and the zincite bornite.

Crystal detectors will receive damped waves only. To receive undamped waves, a vacuum tube or other beat-producing device

must be used. The beats thus produced may be detected by a crystal. An explanation of this phenomenon will be discussed in a subsequent chapter.

The vacuum-tube detector requires a battery for operation and will be discussed in detail in the chapter on Vacuum Tubes.

Function of the Crystal Detector.—The oscillations radiated by the open oscillating circuit of the transmitting set are of a very high frequency. The alternations of the current occur with such rapidity that the positive alternation is followed so quickly by a negative alternation that the effect is a neutralization in the headphone circuit. Such a wave train is shown as curve *A*

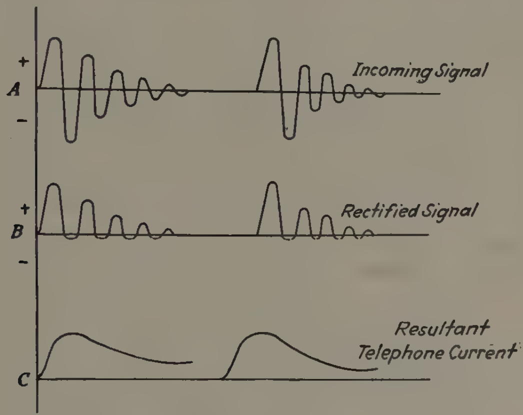


Fig. 108.—Graphs showing rectifying effect of crystal detector.

in Fig. 108. Furthermore, even though the oscillations were sharply defined in the receiving circuit, the diaphragm of the headphone would not be able to vibrate at such a terrific rate. It is necessary, therefore, to gather together all of the alternations in one direction, absorb their resultant energy, smooth it out in the form of one pulse, and send this pulse through the headphone to be made audible. The diaphragm of the headphone can only vibrate at those frequencies that are audible to the ear. These are called "audio frequencies" and range between 16 to 10,000 sound waves or cycles per second. The rapid radio frequency current has the same effect on the diaphragm as if it were trying to move in opposite directions at the same time and, therefore, no perceptible motion takes place. The incoming wave must be

rectified so that only one-half of its oscillations are sent through the headphones; that is, the upper half is passed through the detecting medium and the lower half is retarded or neutralized. This is done by the detector. The detector detects nothing, strictly speaking, but it does perform the very important function of rectifying, explained above, without which the damped waves would be inaudible, due to their extremely high frequency. Curve B in Fig. 108 shows the rectified wave after it has passed through the detector. Notice that the detector allows the current to pass in practically one direction only. In the case illustrated the current can pass the detector in a positive direction only, and the result is that all of the negative alternations are wiped out leaving a series of positive pulsations.

From the above it is seen that the chief requirements of the detector are that it shall have unilateral conductivity and permit the current to flow in one direction only.

Potentiometer.—Some types of detectors, the carborundum being the most commonly used, require a battery for efficient

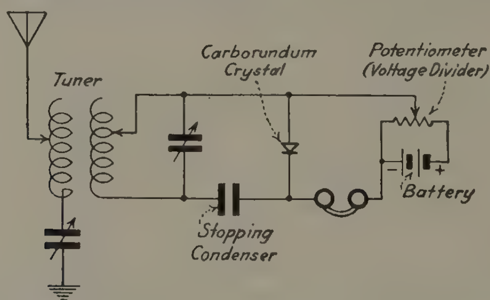


Fig. 109.—Carborundum crystal detector circuit.

operation. The battery current must flow through the crystal in a given direction and at a certain rate. The potentiometer controls the rate of battery current flowing through the detector crystal and is connected in the circuit as shown in Fig. 109. The potentiometer, or, strictly speaking, the "voltage divider" is used to bias or control the biasing voltage which causes it to function with maximum sensitivity. Note that the fixed condenser marked "stopping condenser" is so placed that it stops the battery current from flowing into the inductance coil of the

receiver. The theoretical action of the carborundum crystal as a rectifier with the external electromotive force is highly technical in nature and will not be discussed. It is sufficient that the operator know that the efficiency of the detector is increased by the application of the external electromotive force and the methods of connecting the apparatus involved.

Potentiometers are constructed by using high-resistance wire such as German silver or by using a graphite rod. A movable contact is provided which slides over the resistance unit, and in this way the resistance value used is varied. Potentiometers for use with carbonrundum or "Perikon" detectors (bornite zincite) may have a resistance as high as 5,000 ohms. Because of its high resistance, the potentiometer does not discharge the battery rapidly, although it is connected directly across it. The impressed voltage depends upon the position of the sliding contact on the potentiometer. This is easily understood by referring to the method of connection. If the resistance between the slider and the positive terminal of the battery is less than the resistance to the negative terminal, the current will be large while, on the other hand, as the slider is brought down towards the negative side the current decreases.

Fixed Condenser across Headphones.—The question now naturally arises from the explanation of curves *A* and *B* Fig. 108 given above as to how the final current resolves itself into the curve *C*. A small fixed-capacity condenser of about 0.00015 mf. is connected across the headphones and it has the effect of charging and discharging the oscillations of curve *B* into the headphone in a more or less steadily decreasing flow, as shown by curve *C*. This may be explained as follows: If the principal flow of current is positive and downward through the detector and headphone circuit, the fixed condenser is charged with the top plate positive. Now the instant that the radio oscillations reverse, the fixed condenser discharges and causes a continuation of the downward current flow through the headphone circuit until the next oscillation downward occurs The headphone lead wires sometimes have sufficient capacity in themselves to perform this function. The impedance of the magnet windings also tends to provide inertia which tends to make the rectified oscillations in curve *B* take the form *C*.

In most crystal receiving sets, if the fixed condenser is removed from across the headphone the result is a hollow-sounding note which is unpleasant to hear, at best, and in direct contrast to the mellow, full, and rich note which is heard when the fixed condenser is used. In other words, the small fixed condenser is primarily used to by-pass the high-frequency variations across the high impedance of the headphones, to permit more of this high-frequency signal voltage to act on the crystal and, thereby to improve its rectifying efficiency. For the duration of nearly a wave train it charges and when its voltage or potential is higher than the applied signal voltage, it discharges through the telephones. In discharging it causes one click to be given off by the

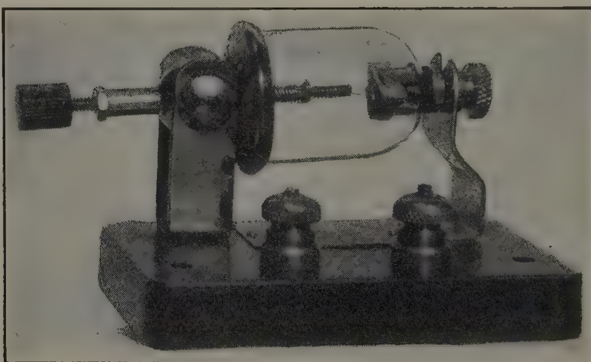


FIG. 110.—Typical crystal detector.

telephones. If, therefore, 1,000 wave trains per second were creating this effect then there would be 1,000 clicks at the same time and a characteristic musical note is heard from the telephones.

Requirements of Detector.—A common type of detector stand is shown in Fig. 110. It consists of a cup to hold the crystal and a spring contact called "cat whisker" arranged so that it can touch any part of the crystal when the crystal is being "explored" for sensitive spots. The detector must be rugged and not easily knocked out of adjustment. This is especially desirable on board ship where the operating table is not always steady. The crystal must be sensitive and readily hold its adjustment even when strong nearby signals are being received. Methods of

protecting the detector against injury from high-powered nearby signals will be given in the discussion on the operation of complete receiving sets later on.

The crystal detector has been largely replaced by the vacuum-tube detector on all modern receivers.

The Telephone.—The function of the telephone receiver is to make audible the rectified high frequency oscillations. Headphones used in ratio work are known as the watchcase type, and are constructed as in the illustration Fig. 111, which is properly labeled. They are especially sensitive to the weak currents in a receiving set. A close study of this figure will show clearly the component parts of this instrument. Under normal

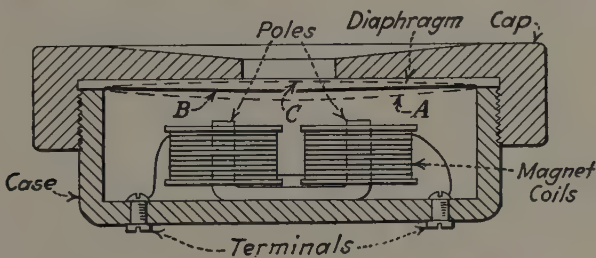


FIG. 111.—The telephone receiver.

conditions the diaphragm is in position *B*. When a current flows through the electromagnetic coil windings, however, the diaphragm vibrates within the limits of the dotted lines *A* and *C*, depending upon whether the current in the windings at a given instant is aiding or bucking the effects of the permanent magnets themselves. The diaphragm is like the head of a drum, and it takes a very little shock to make it respond loudly. Great care must be taken not to bend the diaphragm, as this will make the headphone inoperative. The reason for this is obvious. The distinctive feature of the radio headphone is that it is wound with extremely fine wire, usually No. 40 B. & S. gage, which makes it possible to get a great number of turns in a relatively small space. The magnetomotive force developed by the magnet coils in the headphone depends upon the number of turns on the coil and the amount of current passing through them. The large number of turns results in a relatively large magnetic field being produced, even though only a feeble current is flowing through them. This

feature makes them especially adapted to the weak currents in a radio receiving set. Because it is necessary to wind on so many turns of wire, the radio headphone is graded according to the resistance of its coils. The standard resistance for headphones used in commercial practice is between 2,000 and 3,000 ohms per pair. Such phones consist of two receivers connected in series each with a resistance of 1,000 or 1,500 ohms. There may be as many as 10,000 turns of wire used in making a headphone of this resistance. The resistance is always measured with direct current.

It is obvious, of course, that headphones will respond to audio frequency currents only; and, even if the diaphragm were able to vibrate at the terrific speed of radio frequency it would be above the hearing range of the human ear. There is always one frequency to which the ordinary watchcase type receiver will respond most strongly. This is called its "resonant frequency." Several receivers have been developed in which this resonant frequency can be varied and these are called "tuned" receivers. They are rather delicate for commercial use and are very seldom seen outside of research laboratories.

Functioning of Headphone.—Referring to Fig. 111, which clearly shows the component parts of a headphone of the metal-diaphragm type, it will be noted that the diaphragm is placed directly over the electromagnets. When no current is flowing through the windings of the magnets the diaphragm is in the slightly strained position *B*, due to the permanent magnetic field of the telephone magnets. However, when a current flows through the windings of the magnets, the diaphragm is drawn towards them to the position *A*, and, as soon as the current pulse has passed it springs slightly beyond point *B*, due to its mechanical inertia. Hence, if a permanent magnet is used it will tend to prevent the diaphragm from swinging too far beyond point *B* and will, therefore, prevent rattling. For example, if a telephone receiver were constructed of a diaphragm and a simple electromagnet no matter in which direction the current passed through the winding the diaphragm would be attracted. Hence, if an alternating current of 500 cycles passed through it the diaphragm would be attracted once for every increase in current or 1,000 times a second. This would obviously result in dis-

tortion, for if one should talk into a transmitter at a certain frequency then the sound in the receiver would be of higher frequency, thus producing an unfaithful signal reproduction.

This disadvantage is greatly minimized by using a permanent magnet so that the core is magnetized in one direction constantly. Hence, the diaphragm will be continually in a bent position and thus if a current passes through the winding in one direction it will add to the flux (magnetic lines of force) of the permanent magnet and bend the diaphragm still more. Then when the current through the winding reverses the flux of the permanent magnet will be weakened and the diaphragm will be released somewhat from its normal position. Thus the action of the 500 cycle current will now produce a movement of the diaphragm one way on one half cycle and the other way on the other half, and the air pulsations will then occur 500 times a second and natural sounding speech will result.

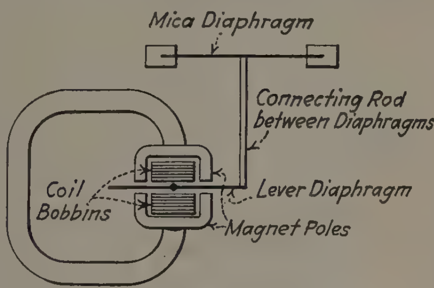


FIG. 112.—Mica diaphragm receiver.

Baldwin Receiver.—This type of phone is known generally as the *mica diaphragm* phone. It differs from the ordinary headphone in that a non-metallic diaphragm, instead of the usual thin metallic diaphragm used in the headphones described above, is used. In principle it is constructed along the lines of a phonograph reproducer, in that the diaphragm is actuated by a lever which is fastened to a movable iron armature placed so that it is affected by the magnets of the headphone. The whole design of this type of phone is quite different from any other type as there is no constant pull on the diaphragm; it rests in its natural position until a current flows through the magnet windings.

There are several advantages of importance claimed for this headphone, the most prominent being that the magnetic circuit is of high permeability and thus small signal currents will produce relatively greater fluxes and greater forces. Another advantage is that the armature is similar in its mounting to a lever with a force acting on each end, thus increasing the deflection for a given magnetizing force, thereby giving greater signal strength.

The *loud-speaking* attachments for amplifying horns or phonographs embody similar features. These devices are usually built in the watchcase form, with either the movable iron armature attached to a lever or an armature coil of fine wire moving up and down in the air gap and attached to the diaphragm by a small rod. Care must be taken in handling telephones to preserve the magnetism, because the sensitivity will be seriously impaired if the magnets are subjected to jarring or dropping.

RECEIVING CIRCUITS

Direct-coupled Receiver.—Shortly after the discovery of the single-circuit receiver, explained previously, the problem of interference presented itself. It was quite evident that if radio was to be of value to the commercial world it would be necessary to eliminate this interference. To meet this problem, the two-circuit receiver was developed.

In the single-circuit receiver the detector is directly connected in the aerial and ground circuit; the resistance, therefore, of the detector affects the oscillating characteristics of the circuit to the extent of making it tune very broadly.

By providing a low resistance path for the aerial and ground circuit, the circuit tunes more sharply; it does not respond to such a wide range of wave lengths simultaneously. This can be done by using the direct-coupled two-circuit receiver circuit shown in Fig. 113. Here is provided an open oscillating circuit from the aerial through point A, through the tuning coil to the ground point B, and a closed oscillating circuit from point C, through the detector and headphone, through point B, the tuning coil back to point C. The turns A to B are common to both circuits. In this receiver the open and closed oscillating circuits are directly coupled. The coupling is called direct because part of the energy from the open circuit to the closed circuit is by direct conduction and part by electromagnetic induction.

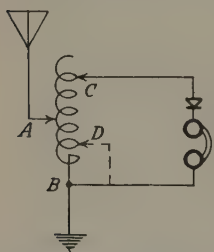


FIG. 113.—Direct or conductively coupled receiver.

Note that two movable contacts A and C are required to tune the circuits to resonance. The coupling on a two-contact tuner is not adjustable. To make the coupling adjustable the lead from

the headphone, which in the diagram connects to point *B* may be connected to a multiple switch or slider as indicated by the dotted lines to point *D*. If this extra contact is provided, the number of turns common to both circuits may be varied and the coupling adjusted.

Bear in mind that coupling variation means a variation in the number of lines of force which link the primary and secondary circuits. When the linking is maximum the coupling is tight or at a maximum. As the number of linking lines are reduced the coupling becomes looser or decreases towards the minimum. With the above in mind it is easy to see that the *CD* circuit may be moved into or out of the *AB* circuit, thereby varying the coupling. Methods of using coupling in the practical operation of receivers will be discussed later.

Inductively Coupled Receiver.—In this type of receiver (Fig. 114) all of the energy is transferred from the primary to the second-

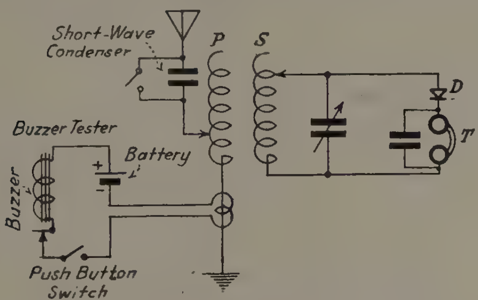


FIG. 114.—Inductively coupled receiver.

ary circuits by electromagnetic induction. The coupling may be easily varied by moving the relative positions of the coils. Usually the primary is stationary and the secondary movable, although actually it makes no difference which coil is movable. There is no metallic connection whatsoever between the open (primary) and closed (secondary) circuits in the inductively coupled receiver.

The advantage of this type of receiver over the direct-coupled set is that it is possible to increase selectivity without decreasing the loudness or audibility of the signals. The variable condenser shunted across the secondary makes it possible closely to adjust the secondary to the desired wave length and also facilitates tuning.

The distinctive feature is the ease in adjusting the coupling. The aerial and detector circuits, furthermore, may be tuned independently. The result is a receiver which is easily tuned and which is quite selective even in districts where interference is heavy.

Capacity-coupled Receiver.—It will be remembered that, in the direct-coupled receiver, the energy is transferred from the primary to the secondary partly by direct conduction and partly by electromagnetic induction, and that in the inductively coupled receiver, just explained, it is transferred by electromagnetic induction only. The third and final type of coupling to be considered is known as capacity coupling. This receiver also provides distinct primary and secondary circuit coils which allow separate tuning of the aerial and detector circuits. The coupling, however, is accomplished by condensers, as shown in the diagram of this type of receiver (Fig. 115).

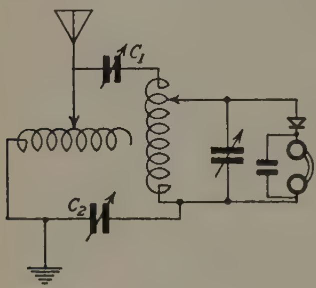


FIG. 115.—Capacitively coupled receiver.

In this type of receiver the primary and secondary coils are permanently fixed and placed at right angles to each other. By this method of construction, compactness and ruggedness may be had. This type of receiver does not tune as sharply as the inductively coupled type.

Coupling is accomplished by the coupling condensers C_1 and C_2 which are on the same shaft and adjusted together.

It is usually the practice to wind the inductance coil in rectangular or square winding sections or lap-wound circular coils. These windings take up very little space.

Capacity coupling is also referred to as electrostatic coupling.

Tuning.—In order that receiving sets may respond efficiently to the transmitted signal they must be tuned. By tuning is meant adjusting the set so that interfering stations are eliminated and the desired signals brought in loud enough to be read by the operator. Tuning a receiver requires three adjustments: (*a*) adjustment of inductance, (*b*) adjustment of capacity, (*c*) adjustment of coupling. The single-circuit receiver is the simplest to

tune, as there is only one circuit to be adjusted. Due to its inability to tune sharply, however, it has given way to the various types of two-circuit receivers just described. Tuning the two-circuit receiver involves (*a*) tuning the open oscillatory circuit, called the primary, and (*b*) tuning the closed oscillatory circuit, called the secondary. Note that in the receiver the primary and secondary are the reverse of the primary and secondary in the transmitter. In the receiver, the aerial circuit is the primary while in the transmitter it is the secondary. This follows, in that the primary is always the circuit in which the oscillations are started and from which the secondary current is induced.

When the primary and secondary circuits have been tuned, and this is done when using close or tight coupling, the coupling is decreased as much as is necessary to tune out interference. Reducing the coupling in some cases increases the signal strength with a given setting on the receiver.

As a practical example, the operation of the inductively coupled receiver, shown in Fig. 114, will be considered here. To tune in a given station the following operations are performed.

1. Set the crystal detector with the aid of the test buzzer.
2. Tighten the coupling by bringing the primary and secondary coils close together.
3. Adjust the aerial or primary circuit to resonance with the desired station. This is done by varying the amount of inductance in use. If a short wave condenser is connected in this circuit, it must either be short-circuited or carefully adjusted.
4. Adjust the secondary or detector circuit until the signals are as loud as possible. This is done by varying the amount of inductance in the secondary. With close coupling the variable condenser should be at a minimum capacity, and as much tuning as possible done with the inductance switch. When the signals are the loudest the secondary condenser may be adjusted for further increase in intensity.
5. Loosen the coupling, at the same time increasing the capacity of the variable condenser across the secondary, until any undesired signals are eliminated.

In general, louder signals are obtained when using a maximum amount of inductance and a minimum amount of capacity. It is always well to work with close coupling when receiving distant stations, and unless interference prevents it. If interference is liable to occur it is wise not to take a chance on

having to ask for a repetition: it is much better in that case to use loose coupling at the expense of signal strength. The operator will soon learn this after working with commercial traffic.

Questions

1. Draw a diagram of a direct coupled receiver.
2. How is the coupling varied in the above circuit?
3. What is the disadvantage of this type of circuit?
4. Draw a diagram of an inductively coupled receiver with crystal detector and telephones.
5. How would you adjust the receiver to a given signal?
6. Draw a diagram of a simple radio receiver.
7. How are the high-frequency signals rendered to audibility?
8. Describe the electric and magnetic operation of the head telephone.
9. What are the usual resistances of telephones used on shipboard?
10. What is the function of the telephone condenser?

CHAPTER XVII

THE VACUUM TUBE

Introduction.—The vacuum tube is a highly technical piece of radio apparatus and a thorough discussion and study of this instrument is here covered in a way complete and comprehensive enough for the use of the commercial radio operator and for the government license requirements.

Vacuum-tube Receivers.—On first consideration, the understanding of vacuum tubes will appear very difficult to the student, but it is necessary that the radio operator have a knowledge of the working of this apparatus as used in commercial radio stations. No attempt is made in this text to cover all the phases of the uses or possibilities of vacuum tubes in radio work, but some fundamental principles and circuits are developed which it is necessary for the operator to know about. Vacuum tubes are variously called "vacuum valves," "electron tubes," or "audions."

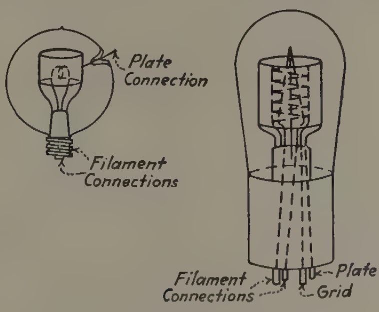


FIG. 116.—Vacuum tubes.

Fleming Valve.—The original vacuum tube was invented by Dr. J. A. Fleming in London and was called by him an "oscilla-

tion valve." In construction it looked like the early type electric light bulb and was, in fact, the same with an extra element in the form of a metallic plate which was called the "plate." It is referred to as the "two-element" vacuum tube. It was called a valve because of its ability to permit the passage of electricity within itself under certain conditions, opening and closing the electric circuit like a valve. The theory of its operation will be explained further on in this text. The Fleming valve is shown together with the modern vacuum tube, in Fig. 116. Note carefully the construction of each. The three-element tube is a vast improvement over the original two-element Fleming valve.

Vacuum Tube.—The distinctive difference, electrically, between the Fleming valve and the modern vacuum tube as developed originally by Dr. DeForest in the United States is the addition of the third element called the grid. A study of Fig. 116 will show how the vacuum tube is made. Note that it has three elements: filament, plate, and grid. It is very rugged and will withstand moderately hard usage.

There is as near a perfect vacuum within the tube as it is possible to attain. The degree of vacuum necessarily differs in different tubes, depending upon the use to which they are to be put. If a tube has an extremely high vacuum it is called a "hard tube;" on the other hand, if the degree of vacuum is not so high it is known as a "soft tube." Soft tubes make the best detectors when carefully operated while the hard tube serves best as an amplifier and oscillator. The hard tube may, if necessary, be used as a detector.

Filament.—The filament in the vacuum tube is of thoriated tungsten or oxide and is similar to the ordinary electric light. The tube filament is heated by a direct current supplied by the A battery. The voltage necessary to light the filament depends upon the type of tube and varies from 1½ volts, a dry cell, to 10 or more volts.

Plate.—The plate is constructed of molybdenum, nickel, or thin sheet steel. It usually takes the form of a rectangular cylinder which encloses the filament and grid. This, however, is not always the practice; as it sometimes takes various rectangular or square shapes.

Grid.—The grid takes the form of a wire mesh or is wound in the form of a small helix. It is always placed between the filament and the plate and acts as an obstruction or booster to the current passing between the filament and the plate.

Base.—The types of vacuum tubes used for receiving purposes and the smaller-sized transmitting tubes are fitted with an insulator base on which is provided four prongs, two for the filament and the remaining two connecting to the plate and the grid respectively.

Edison Effect.—Inside the vacuum tube is a vacuum, and the flow of electricity through this is termed the "Edison effect." This was discovered by Edison many years ago. It is only since the advent of the vacuum tube, however, that this effect has been put to practical use.

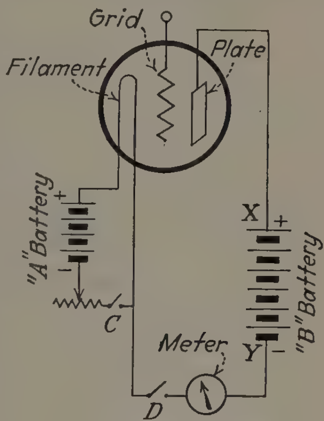


FIG. 117.

Experiment.—To understand clearly the Edison effect, let us look at Fig. 117. Here is shown a vacuum tube with the A battery connected so that it will light the filament. For the time being the grid will be disregarded.

Next direct attention to the B battery; notice that it is connected with its positive pole to the plate and its negative pole through a current indicating device to the filament.

The switch *C* controls the filament current and the switch *D* the plate current, as the B battery current will be called. With both of these switches open nothing happens. When *C* is closed the filament lights.

DEMONSTRATION

Condition	Result
1. All switches open.	Nothing happens.
2. *C* open *D* closed.	Nothing happens.
3. *C* closed *D* open.	Filament lights.
4. *C* to remain closed and *D* closed.	A deflection will be noted on the meter.
5. Reverse B battery connections *X* and *Y*. Filament still lit.	No, or very little, deflection on meter.

The above demonstration clearly shows that when the filament is lit a current of electricity passes through the B battery circuit traversing the space between the filament and the plate. It also shows conclusively that this occurs only when the positive side of the B battery is connected to the plate and that the effect is lost if this connection is reversed.

Electron Emission from Hot Filament.—As soon as the filament of the vacuum tube is heated, it sends out a stream of electrons which are known as negative electrons. These electrons are attracted to the plate which is positively charged by being connected to the positive terminal of the B battery. The fundamental rule of "like charges repel, unlike charges attract," holds absolutely true.

The electrons emitted from the filament bombard the plate and flow through the *B* battery and return to the filament. This flow of electronic current constitutes the plate current.

This statement is usually confusing to the beginner because of the conventional theory that electricity flows from the positive terminal of a battery to the negative terminal. Although this latter theory is generally accepted it is not true. There is really only one current flowing and that is the electronic flow from negative to positive. The battery merely supplies the potential which sets the electrons in motion. Furthermore, it is important to remember that, if the plate of the vacuum tube is connected to the negative terminal of the *B* battery, no current flows because the negative electrons are not attracted to the plate (like charges repel each other). However, in order to avoid confusion the reader may assume the *B* battery current to flow from the plate to the filament whenever the plate is connected to the positive terminal and then back to the negative terminal of the battery, thus completing the circuit. This latter conception does not hold true in engineering but is used in practically all elementary studies and is therefore used here for simplicity only.

Effect of Plate Potential on Plate Current.—It is now understood that the only way for the B battery current to get from the plate to the filament is through the stream of electrons which reaches the plate from the filament. If, then, the stream is reduced in volume the plate current will be proportionately reduced.

The filament sends forth its electrons at a certain rate depending upon the potential of the plate itself in respect to the filament and upon the brilliancy at which the filament is burning. It is easily conceivable that there will be a point, assuming that the plate has a high potential, when it will be attracting all of the electrons which leave the filament. In this case, an increase in plate potential cannot result in a heavier electronic flow from the filament because all of the electrons leaving the filament are already reaching the plate. In this case, therefore, increasing the plate current or potential will not result in a larger plate current. Remember, the amount of current in the plate circuit is governed absolutely by the electronic stream from the filament to the plate and in this case this electronic stream has not been increased.

Now then, suppose that the filament is burning at full brilliancy and sending forth a maximum number of electrons. In this case assume that the plate potential is low in respect to the filament. The electrons leaving the filament, therefore, will not all be attracted to or reach the plate. Some of the electrons return to the filament or, in other words, are wasted. The result is that the path for the plate current, from the filament to the plate, is not a good one and the plate current, therefore, is small. Now, if the plate potential is increased by applying a higher voltage to the plate, more electrons will be attracted to it and the stream of electrons from the filament to the plate will be increased. As the stream is intensified, it can carry more current, just as a large pipe can carry more water than a small pipe. The result is a larger plate current. To sum up the above: An increase in plate potential will in some cases increase plate current and vice versa. It is always true, however, that a reduction of plate potential will decrease plate current as soon as the potential of the plate falls so low that the intensity of the electronic emission from the filament to the plate is reduced.

In practice, it is desirable to burn the filament at a moderate temperature and control the plate current by the proper adjustment of plate-battery voltage. The life of the tube is only as long as the life of the filament and it is, therefore, economical to be careful about the brilliancy at which the filament is burned. In a previous paragraph it was stated that the vacuum tube

should be exhausted as near to a perfect vacuum as it is possible to attain. The presence of atmosphere or other gases has the effect of lowering the efficiency of the tube by a phenomenon known as ionization by collision. In a rarefied gas, there are electrons present some of which are free and some of which are parts of the atoms of the gas. The free electrons dislodge the gas electrons by collision and acquire great velocity in a direction controlled by the e.m.f., between the filament and the plate. These new electrons become carriers of electricity and result in a large plate current in a tube with poor vacuum. This appears to be an advantage, and some of the earlier experimenters really encouraged this additional electronic flow, but the filament deteriorated very rapidly due to the bombardment of the positively charged "ions" of gas. It is difficult to use two or more tubes with poor vacuum in parallel, as their electrical characteristics vary with the degree of vacuum, while tubes with high vacuum can be paralleled without difficulty.

Effect of Filament Current upon Plate Current.—This effect was discussed in effect in the preceding explanation but in order that it may be clearly understood let us assume a concrete example.

Suppose the plate is at a potential great enough so that it can attract 2,000 electrons per second from the filament. Suppose the filament is emitting 1,000 electrons per second. Each electron as it leaves the filament carries a negative charge and, therefore, in this case, the space between the filament and the plate will be charged negatively to the value of 1,000 units while the plate is charged positively to the value of 2,000 units. The result, therefore, is that the plate charge is stronger than the space charge and all of the 1,000 electrons which leave the filament per second are attracted to and reach the plate.

Suppose, further, that the filament temperature is raised so that 1,500 electrons are emitted. The space charge is then 1,500 units negative and the plate, still remaining at 2,000 units positive attracts all of the electrons emitted by the filament.

Suppose now the filament temperature is raised so that 2,000 electrons are emitted making the space charge 2,000 units negative as against the plate charge of 2,000 units positive. The plate still attracts all of the 2,000 electrons emitted by the

filament but a saturation point for this plate potential has been reached; the space charge now equals the plate charge.

Up to this point there has been an increase in plate current for every increase in filament current (resulting in more electrons being emitted by the filament) because the path (the electron stream) between the filament and plate has been increased.

Now suppose that the filament temperature is increased so that 2,500 electrons are emitted. The space charge is 2,500 units negative as against the plate charge of 2,000 units positive. The result is that 500 electrons are repelled back to the filament—lost as far as effect is concerned. Any further increase in filament temperature would be useless, as all electrons over the 2,000 limit, which the plate will attract, are useless in effect. Therefore, increasing the filament current does not result in an increased plate current as long as the plate current remains at the point where the plate attracts only 2,000 electrons.

If the plate voltage is increased and the positive potential of the plate raised so that it will attract more than 2,000 electrons an increase in filament current will result in a proportional increase in plate current. In general the plate current is dependent upon the filament current, but the plate current has no electrical effect upon the filament current as the filament could burn even though the plate be entirely removed from inside the tube.

Extreme care of voltage regulation must be taken with tubes using thoriated tungsten filaments. If the voltage is adjusted above the designed working voltage of the tube, the filament may become deactivated which will, in time, result in a decrease in the electronic emission and, hence, would produce a decided decrease in the signal intensity.

Grid.—The grid, as has been stated before, in all types of vacuum tubes used at the present time, is placed between the filament and the plate. It is not absolutely necessary that the grid be placed in this position for it would affect the operating characteristics of the vacuum tube even if it were placed on the other side of the filament opposite the plate, but its effect in this position would not be nearly so great as when it is placed between the filament and the plate.

When the vacuum tube is in operation, the space between the filament and the plate carries what is called a "space charge."

The function of the grid is to control the potential of this space charge. When the grid is positive it decreases and when it is negative it increases the space charge. It is to be remembered that the electronic emission from the filament to the plate is controlled in quantity by the condition of this space charge.

To understand clearly the action of the grid on this flow of electrons, refer to Fig. 118, which shows the grid connected to a C battery. A potentiometer is connected in shunt to the C battery so that the potential of the grid may be made either positive or negative at will by moving contact 1.

Assume that contact 1 is halfway between the positive and the negative sides of the C battery, marked *O* on the potentiometer. The potential of the grid is then zero.

Now suppose that the filament is emitting 2,000 electrons per second and the plate potential is such that the plate attracts all of the 2,000 electrons, and the meter registers, let us say, 10 milliamperes current in the plate circuit. If the grid is now charged with a negative potential by moving contact 1 to the right, the current in the plate circuit immediately starts to decrease, because the positive effect of the plate potential is being bucked by the negative effect of the grid, and the resultant value of the space charge is increased. It is evident that if the grid is charged isufficiently with a negative potential it can be made to neutralize totally the positive plate potental and no current would flow in the plate circuit.

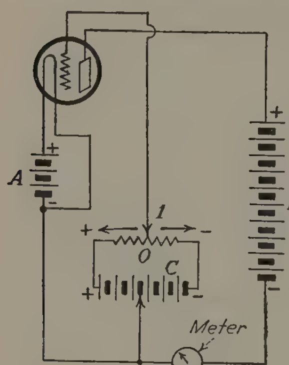


FIG. 118.

To take the converse of the above experiment, suppose first that the plate potential remains the same, so that the plate still attracts 2,000 electrons when the grid is at zero potential. The filament temperature is increased so that the electronic emission is raised to 2,500 per second. If contact 1 is moved to the left and the grid potential made positive, the plate-current reading on the meter will immediately rise, indicating that the plate is attracting more than 2,000 electrons. This is true

because the positive potential of the grid has augmented the plate potential and partially neutralizes the space charge—thereby making it possible for the plate to take more than 2,000 electrons as was originally the case before the grid charge was introduced into the space between the filament and the plate. The grid, therefore, either increases or decreases the plate potential and directly affects the value of the plate current.

Characteristic Curves.—The effect of the grid potential on the plate current may be plotted on cross-section paper as in Fig. 119. This is known as a characteristic curve for the vacuum tube used in taking the measurements.

The grid potential is plotted along the base, or abscissa, of the cross-section paper, and the plate current is plotted as the ordinate, or vertically. By referring to the curve, it is seen that when the grid potential is zero the plate current is 0.5, for this is

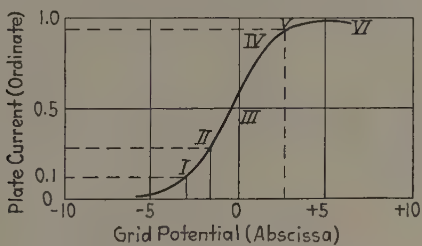


Fig. 119.—Characteristic curve.

the value of plate current when reading from point III on the curve. Notice that the vertical line passing through point III on the curve reads zero on the abscissa and 0.5 on the ordinate. Now, if the grid potential is adjusted to 5 units negative the plate current is very nearly neutralized, the ordinate reading close to zero. If the grid potential is adjusted to 2½ units positive the dotted line running from the abscissa to the curve, point V indicates almost 1 unit plate current. On the straight part of the curve II to IV the plate current is directly proportional to the grid potential.

From the study of the above action, it is seen that if an alternating potential is impressed on the grid the plate current will rise and fall uniformly. This is exactly what happens when the vacuum tube is connected in a radio receiver as a detector, as

the potential impressed on the grid by the arriving radio waves is alternating in nature.

Saturation.—When the value of the plate current is such that the plate attracts all the electrons which the filament emits, a further increase in plate potential does not affect the electronic stream from the filament to the plate and a "saturation point" has been reached. The shape of the characteristic curve depends upon the saturation point.

Questions

1. Describe the two-element valve. The three-element valve.
2. What happens when the filament of a vacuum tube is heated?
3. What effect has the plate potential upon the filament emission?
4. How is the filament of a vacuum tube adjusted to the proper voltage?
5. What is the function of the grid?
6. What effect upon the plate current has an increase in plate potential?
7. What is meant by the saturation point of a tube?
8. What would happen to the plate current if the grid received a heavy positive charge (bias)?
9. What would be the effect if the plate of the vacuum tube received a negative charge?
10. Draw a diagram of a vacuum tube circuit showing the battery connections.

CHAPTER XVIII

THE VACUUM-TUBE DETECTOR AND AMPLIFIER

Plate Rectification.—It has been previously pointed out that the state of the grid charge controls the plate current. If, then, an alternating potential is applied to the grid, as in Fig. 120, the plate current, as indicated by the meter, will vary with the alternations of the grid potential.

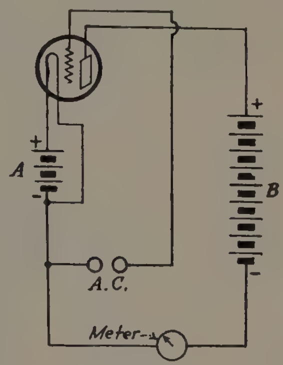


Fig. 120.

When the grid is not charged, a "normal" plate current will flow. When the alternating potential is applied, a plate current above normal will flow when the grid is charged positively, and a plate current below normal will flow when the grid is charged negatively. The tube may be operated so that the increase over normal plate current will be much more than the decrease below normal and the plate current would have a characteristic as shown in Fig. 121. The average plate current, therefore, is greater than normal when the tube is operating under these conditions. When the variations occur in rapid succession

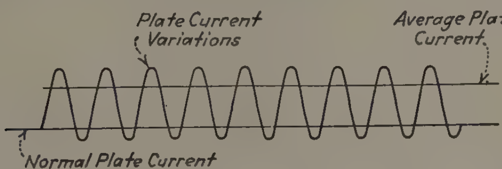


Fig. 121.

the resultant effect is that the alternating current applied to the grid causes the plate current to be "triggered" through the plate circuit at an average value somewhat above the normal plate current. This effect is made use of when the vacuum tube is

used in a radio receiver. It amounts in effect to the rectification of the radio frequency waves into audio frequency impulses so they may be heard in the headphone of the radio receiver.

Vacuum-tube Detector.—Modern radio installations use the vacuum-tube detector almost exclusively. In Fig. 122, the vacuum tube is shown connected up as a detector. The vacuum tube is superior to the crystal detector for two important reasons: first, it is approximately five times as sensitive as the best crystal detector; second, it is permanent in adjustment and does not have to be "set" as the crystal must be. Furthermore, it readily lends itself to further amplification of the received signals by means of additional vacuum tubes which are connected to it as amplifiers. These will be discussed further on in this chapter.

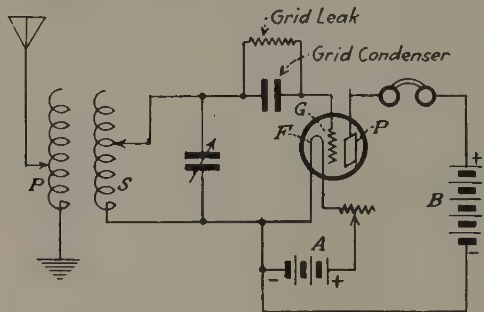


FIG. 122.—Vacuum-tube detector circuit.

The radio waves are impressed upon the primary of the receiving transformer marked *P* and are induced into the secondary circuit. It is to be noted that the grid is now subjected to an alternating potential in the same manner as in Fig. 120, except that it is now subject to radio frequency rather than audio frequency potentials.

The important difference between audio and radio frequency alternating current is that the former alternates anywhere from 30 to 10,000 cycles per second and the latter from 10,000 to 60,000,000 cycles and up per second. There is no sharp defining line between the frequencies and in commercial practice they are usually divided into three groups:

1. Commercial frequencies 30 or 60 cycles. Used in electric light and power work.

2. Audio frequencies, 30 to 10,000 and higher. Within the audible range of the human ear.

3. Radio frequencies, 10,000 cycles and up. Above the range of the human ear. To be heard, this range of frequencies must be broken up into groups at a rate below 10,000 per second.

In Fig. 123 is shown the effect of the vacuum tube on the received radio oscillations. In the top curve the incoming wave trains are seen as a series of high-frequency oscillations which are transferred to the grid circuit by means of the receiving transformer. These wave trains are of radio frequency and are

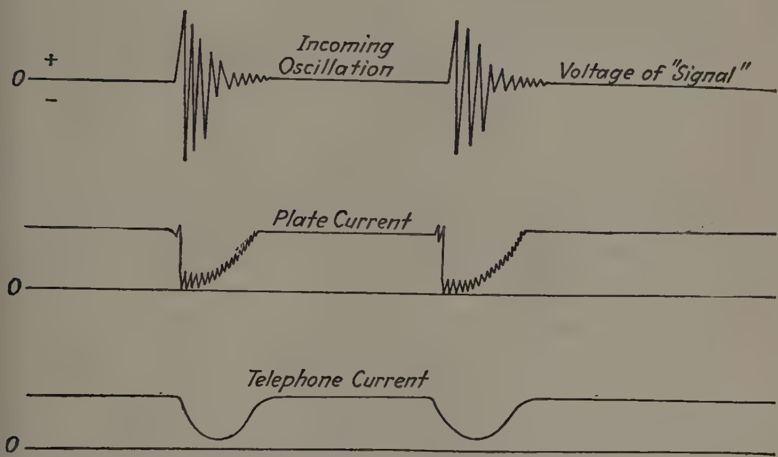


FIG. 123.—Action of detector tube with grid condenser and leak.

inaudible. Their effect on the plate current is shown by the second curve. The frequencies of these incoming wave trains are too great to flow through the windings of the telephone receivers because the inductance is too high to permit them to pass; but they do flow through the capacity of the plate circuit, which consists of the telephone receiver wires or a small condenser shunted across the receivers themselves. The result is a current of a frequency shown by the two lower curves which reach the receivers and are in the range of audible sound.

Grid Rectification.—By connecting the grid condenser in the circuit, the rectifying action of the vacuum tube is considerably improved.

The action of the tube as a detector when the grid condenser and the grid leak are connected in the circuit is an important one and should be carefully analyzed.

Assume that incoming signals have been induced from the primary to the secondary coil and that alternate positive and negative charges have been applied to the grid.

When the grid is positive, the space charge in the immediate vicinity of the filament is neutralized, thereby allowing more electrons to flow to the plate and, incidentally, creating an increase in the plate current. The grid, being in a positive state, also attracts some electrons, but due to the blocking action of the grid condenser these electrons are "trapped" on the grid. It is advisable that the reader bear the picture of this explanation in mind before proceeding.

As soon as the grid receives a negative charge from the incoming wave train the plate current is decreased below normal. Note carefully that the negative charge of the incoming signal is in addition to the electrons which have been "trapped" on the grid from the previous positive charge. This will result in a greater decrease in the plate current than would normally result from the negative charge of the incoming signals alone. The next positive charge of the incoming wave train again increases the plate current and attracts still more electrons to the grid, which are added to those which have previously been trapped.

Note carefully that the negative charge now on the grid has again increased, which results in a still further decrease in plate current. It must also be noted that the plate current almost always increases in the same amount (amplitude) with every positive charge received by the grid, but the decrease for each successive negative accumulation is constantly becoming less. If therefore, this condition persisted the plate current would finally be totally blocked which would result in a spilling-over action which would result in very unstable operation. In order to prevent this condition from arising, a grid leak is placed across the condenser to allow the electrons which have been trapped on the grid to leak off in the intervals between the incoming wave trains. If the above explanation has been carefully followed it will readily be seen, by referring to the figure, that every group of oscillations will produce a "dip" in the

plate current as a result of the negative accumulations on the grid.

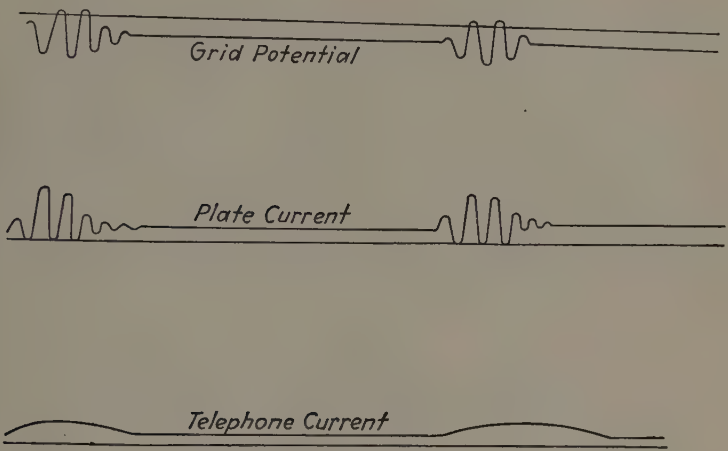


FIG. 124.—Rectification without grid condenser. (Negative grid bias of 2 volts.)

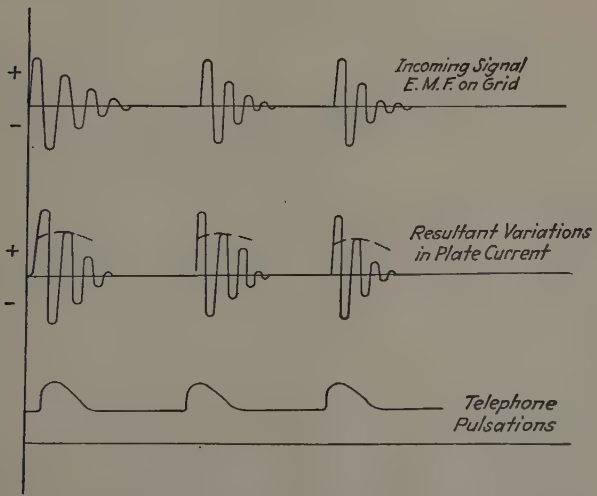


FIG. 125.—Graph of plate rectification without grid condenser.

It is this dip in plate current which results in the audio frequency group pulsations at regular intervals, which produce a response in the telephone.

The curves in Fig. 123 illustrate the detector operation of a vacuum tube with a grid condenser and grid leak, while the curves in Figs. 124 and 125 illustrate the plate action without a grid condenser and grid leak. Note that there is a slight tendency for a higher amplitude in the plate circuit (Fig. 125) when the grid is positive, due to the increase in plate current during the period in which the grid is positive. This results in a slight rectification in the plate circuit which could actuate a telephone diaphram to a small extent.

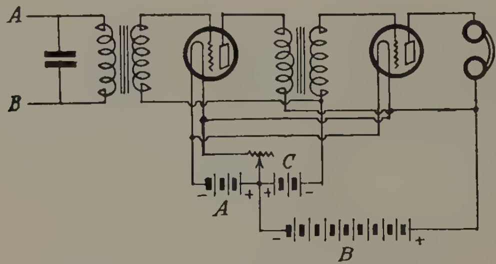


FIG. 126a.—Audio frequency amplifier.

The signal intensity, however, would not be as great as with the condenser and grid leak and this arrangement is, therefore, only used in radio frequency amplifying systems. It is, therefore, advisable to study carefully Fig. 123 for the detector action of a tube when used with a condenser and grid leak.

Audio Frequency Amplification.—Having analyzed how the incoming signals pass through the tuning elements and are rectified by the crystal detector or the vacuum tube brings the observer to the point where a greater amplification of the rectified signal is desired.

Assuming that the signal has been properly rectified by the detector but is not of sufficient volume, it then becomes necessary to amplify the voltage and current variations in the detector circuit up to the desired point where loud signal volume may be obtained.

This particular method of amplifying the current and voltage variations is called audio frequency amplification, and is obtained in the following manner:

The circuit of an audio frequency amplifier is about the most standardized of radio circuits. This is shown in the circuit diagram Fig. 126. It is very simple. The points *A* and *B* are the input terminals of the primary of the first audio frequency transformer and connect into the plate circuit of a detector tube, or into a crystal detector circuit, in place of the head telephone receivers. The audio frequency plate-current variations, which would flow through the telephones, will now flow through this primary which replaces the telephones. The process of amplification takes place at audio frequencies. The voltages are amplified and, in the plate circuit of the second stage tube, the variations of plate current are very much greater than in the plate circuit of the detector tube. Both voltage and current, the power, are amplified to a sufficient degree to give out a greater volume than can be secured with the telephones alone in the detector plate circuit or a crystal detector circuit.

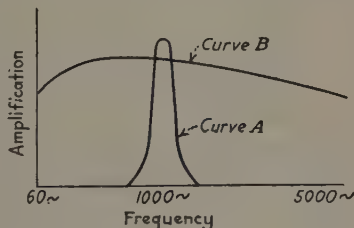


Fig. 126*b*.—Audio transformer curves.

If the grid of one of the amplifier tubes ever actually has a positive charge or voltage on it, there will be a current in the grid circuit which generally causes distortion. This may be prevented by using the grid biasing or C battery shown in the circuit. However, in telegraphic reception it is not desirable to have audio transformers designed for distortion prevention and therefore the grid bias is not essential. In telegraphy, the received audio frequency signal is usually of a 1,000-cycle characteristic, *i.e.*, 500-cycle sparks, continuous wave, with the beat note set to 1,000 cycles, etc., therefore, the transformer should have a more peaked characteristic which will cover the 1,000-cycle notes with maximum amplification. The two curves in Fig. 126*b* illustrate respectively the desirable telegraphic and telephonic conditions of transformers. Note that curve *A* will respond to notes in the vicinity of 1,000 cycles with a greater degree of

volume than will curve B. Curve B, however, would give a fairly even amplification over a band of frequencies which is so desirable in radio telephony.

The advantages of curve A for telegraphy is, therefore, quite obvious if the following facts are considered:

If an audio amplifier is designed to amplify one pitch only, then the turn ratio of the transformers may be increased to a higher ratio, *i.e.*, 9: 1 which will give tremendous voltage amplification of the received signal. Furthermore, if the transformer is *peaked* for a given frequency then the possibility of cutting off line leaks, off-tune signals, and even some static is considerably increased. Thus, allowing maximum signal reception with a minimum of stray interference. However, it is quite possible to have an audio transformer too *peaked* even for continuous wave reception, especially when the wave is unsteady. This would cause a considerable decrease in volume and, therefore, transformers designed for telegraphy have their bands slightly widened to prevent signal cut off.

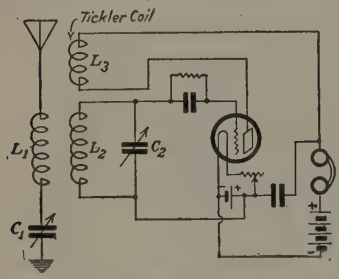


Fig. 127.—Simple regenerative circuit (tickler method).

Regeneration.—The system of regenerative amplification is one of the most important amplifying arrangements in use at the present time.

With it the signal accumulation on the grid of the vacuum tube may be amplified many times. This action must be thoroughly understood in order later to comprehend the action of the tube as an oscillation generator.

Figure 127 illustrates a conventional regenerative circuit, similar in every respect to that of the simple tube detector in Fig. 122, with the addition of a coil L_3 inductively coupled to coil L_2.

The function of the circuit is as follows:

An incoming oscillation of damped or modulated characteristic sets up an oscillatory current in the antenna circuit L_1C_1 under the general conditions of resonance. Through the inductive coupling of the antenna and secondary circuit, energy is

transferred to L_2C_2 by electromagnetic induction of a damped or modulated oscillatory character. Then, the resulting alternating difference of grid potential of the tube produces pulsations or the plate current at the same frequency as the oscillations in the tuned secondary circuit L_2C_2. In other words, an alternating current is superimposed on the normally steady plate current. This alternating current, now flowing through the coil L_3, induces into coil L_2 an e.m.f. in phase with the oscillatory e.m.f. in circuit L_2C_2. This results in a *feed-back* action from the plate circuit to the grid circuit by means of induction from coil L_3 to L_2 due to their mutual relation. If, therefore, it is assumed that a certain amount of signal energy has been dissipated in the resistance of the antenna and secondary circuits, then the energy supplied to the plate is of a lower amplitude and, therefore, under normal conditions would result in a weak plate pulsation and obviously a weaker signal. However, if this energy passes through coil L_3 it can be induced into L_2, and, having gained slightly in amplitude due to the amplifying action in the plate circuit, the signal is actually fed into the grid with a reinforced amplitude. This action of feed-back is nothing more than a grid reinforcing action of grid variations and, consequently, partly compensates for some of the resistance losses in the circuit. The duration and amplitude of the incoming wave trains, as impressed upon the grid of the tube, are thus increased, causing a greater plate current variation and amplitude, and a correspondingly louder signal will be heard in the telephone.

Perhaps the simplest definition for the term *regeneration*, as applied to vacuum tubes in which energy is fed back from the plate circuit to the grid circuit by a coil inductively coupled to the secondary, is as follows:

Regeneration may be defined as that phenomena whereby the grid potential variations due to the incoming signal are reinforced by reactions within the tube circuit itself.

There are various methods by which energy may be transferred from the plate to the grid circuit to create reinforced grid potential variations.

Some of the more important are as follows:

Figure 127 illustrates a coil feed-back system in which the coil L_3 is inductively coupled to the secondary circuit L_2. This is termed the "tickler method" for producing regeneration.

Figure 128 illustrates the *capacity feed-back* system. Here the condenser C^3 feeds the radio frequency variations of the plate circuit to the grid in conjunction with L_3 through the capacitance of the condenser. Here C_3 acts as the radio frequency controlling medium.

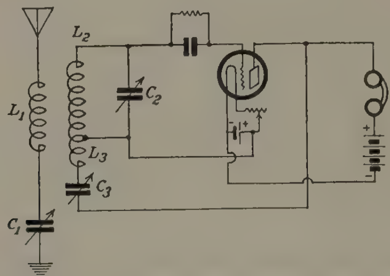


FIG. 128.—Regenerative circuit (capacitive feed-back method).

Figure 129 illustrates a form of regeneration known as the "tuned plate" system. Here the internal capacity of the tube between the grid and the plate allows the radio frequency variations in the plate circuit to feed to the grid whenever the induc-

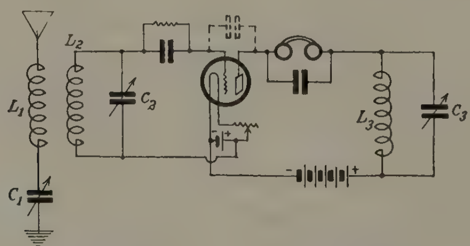


FIG. 129.—Regenerative circuit (tuned-plate method).

tance of the plate circuit is of a value which equals the grid circuit. In other words, when the plate circuit inductance and capacity L_3C_3 are tuned to the same frequency as the secondary circuit L_2C_2, then the tube capacity offers zero reactance to the two e.m.f.'s and a current will flow through the tube capacity. Therefore, for every change in the circuit L_2C_2 there will be a regenerative action, provided, the inductance L_3C_3 is adjusted to the same frequency, or nearly so, to that of L_2C_2. Some feed-back

may also result when these circuits are out of resonance, due to the internal tube capacity, but not at a maximum amplitude.

It can readily be seen that signals of feeble amplitude impinged on the grid of a tube can be reinforced to a tremendous degree by the application of one of the above mentioned systems of regeneration.

Summarizing the above explanations, it is quite evident that the increase in signal volume due to the feed-back action is really a result based on the theory of damping. It will be recalled that every circuit loses a certain amount of energy, due to the dissipation in the form of heat. If, therefore a wave having an amplitude, as in Fig. 123a, is reinforced by regeneration, the duration and amplitude of the wave will be increased to a certain degree, depending upon the intensity of the feed-back. This simply illustrates that the damping of the wave in the circuit is actually prolonged by the regeneration factor overcoming the circuit resistance.

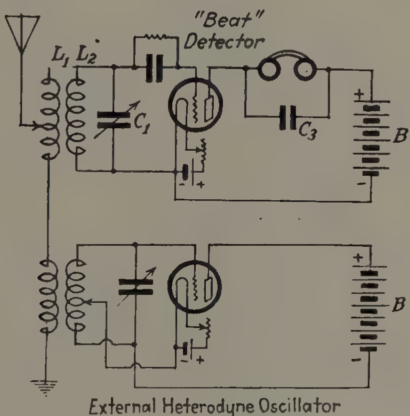


FIG. 130a.—Heterodyne oscillator with beat detector.

This action of the tube to overcome the resistance by feed-back opens the possibility for the tube under suitable conditions, constantly to reinforce the grid and, consequently, produce in itself waves of an oscillatory character in the form of continuous waves.

This action will be described under the chapter on the Vacuum Tube as an Oscillation Generator.

Hetrodyne Effect.—If two alternating currents of different frequencies are impressed upon a given circuit the resultant current takes the form of "beats." As an example, refer to Fig. 130*a*, which shows an external oscillating circuit coupled to a vacuum-tube detector receiver. If the frequency of the oscillations coming in the aerial circuit is 500,000 cycles per second and the frequency of the local oscillator is 501,000 cycles per second, the frequency impressed on the detector is the difference between the two, or 1,000 per second. This is called the heterodyne receiver and is credited to Professor Fessenden, an American inventor. Modern vacuum-tube circuits using the *feed-back* circuit make the external oscillator unnecessary and as this is the only circuit used in modern receivers all further discussion will be on this type.

Autodyne Action.—If the regenerative receiver is to be used for the detection of undamped or continuous waves it is necessary that the coupling between the plate and the grid be close enough to set the local circuit in oscillation for the production of the *beat* effect. This is called the "self-heterodyne" or "autodyne" receiver. The local oscillations meeting the incoming oscillations results in the third frequency being set up. It is, therefore, unnecessary to employ an external oscillator for the reception of undamped waves. A simple analogy of sound beats can be had if the student will picture two hammers striking an unequal number of blows per minute. If one strikes 100 blows per minute and the other 110 blows per minute there will come an instant when each will strike simultaneously. This instant will occur regularly in this case about 10 times per minute and the sound of the blows will be increased at this instant due to the impact of both hammers. At other times the hammers will fall irregularly, gradually approaching and passing away from the instant that they strike or beat together. This is the effect of the autodyne method of beat reception.

This may be more clearly understood if it is remembered that the undamped waves coming in the aerial circuit from the distant transmitter are of a radio frequency, and therefore, inaudible to the human ear. Imposing another radio frequency current in

the same circuit by causing the local vacuum-tube circuit to oscillate at a slightly different frequency, say a difference of 1,000 cycles, causes this difference, which is of audio frequency, to be heard in the headphones.

The autodyne circuit is the same as the regenerative circuit, except that in the former the local vacuum-tube circuit is oscillating and may then be used for the reception of undamped waves.

The pitch of the note heard from the headphones in the external or self-hetrodyne (autodyne, Fig. 130*a*) circuit depends entirely upon the difference between the frequency of the incoming waves and the local oscillations and it is, therefore, possible to change the pitch by changing this difference. This may be done by adjusting the local oscillator.

As an example, if the incoming frequency is 500,000 cycles per second and the local frequency 501,000 cycles per second, the note heard in the headphones is of 1,000-cycle pitch. If the incoming frequency remains the same and the local frequency is changed to 501,500 cycles per second, the note heard is of 1,500-cycle pitch—slightly higher than the first note.

RADIO FREQUENCY AMPLIFICATION

Take, for example, a detector tube with 1 or 2 stages of audio frequency amplification and imagine a feeble signal from a distant station impinging on the grid of the detector tube. This minute potential may be so small that it cannot effect any appreciable variations in the plate circuit and consequently no signal can be heard, no matter how much audio frequency amplification is put on. Why not then amplify these Radio Frequency variations before they get to the detector tube so that when they do arrive there they are of increased amplitude and can appreciably vary the plate current and then amplify this detected signal through the audio frequency transformers until the desired volume is obtained? Thus a means is devised whereby the signal may be amplified at radio frequency through a number of tubes and then detected. This method is the one most extensively used today especially in nearly all radio compass receivers and comes under the heading of Radio Frequency Amplification.

This type of amplification is divided into two groups, *i.e.* untuned and tuned radio frequency amplification, and will be described in detail. The former method will be treated briefly, due to its limited use, through the advent of the more efficient type of tuned radio frequency amplification.

Untuned Radio Frequency Amplification.—Instead of the usual regenerative method of radio frequency amplification, a cascade method may be used with a potentiometer in the circuit of the first tube to control regeneration. The circuit is shown in Fig. 130*b* for two *stages* of radio frequency amplification with a tuned secondary circuit. The object is generally to reduce the number of tuning controls, and it is seldom that its sensitivity

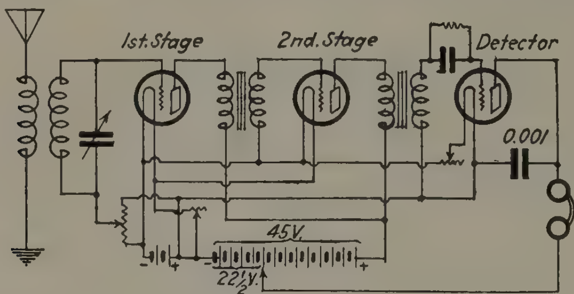


FIG. 130*b*.—Untuned radio frequency circuit.

is any greater than a good regenerative circuit. The circuit is rapidly becoming more or less obsolete. When the sliding contact arm is closest to the negative terminal of the potentiometer, regeneration is at a minimum. When it is nearer the positive terminal regeneration is increased. Regeneration may, therefore, be controlled by adjusting the potentiometer.

Tuned Radio Frequency Amplification.—The purpose of all radio frequency cascade amplifiers is the same as that of regenerative circuits—to amplify the high-frequency voltages in the tuned secondary circuit. In the tuned radio frequency the amplification is increased above that possible with untuned circuits in general. Selectivity is also usually much improved. If the primary of an air-core transformer or *stage coupler* has comparatively few turns, there will be little tendency for the circuits to over-regenerate, although they may regenerate slightly. The

secondary may then have more turns and be tuned by means of a variable condenser, as shown in the circuit (Fig. 130*c*). Two stages are quite commonly used, a third stage usually complicates tuning. There are already, in two stages, three tuning adjustments to make. Since this circuit is in considerable use and is a good one, its action will be described in some detail.

First, in operation, the three tuned secondary circuits must be tuned to resonance with the desired station. It will be noted that the antenna circuit is untuned. It is of advantage to have a variable coupling, but it is not a necessity, and in many cases is left at some fixed value, supposed to be a good average.

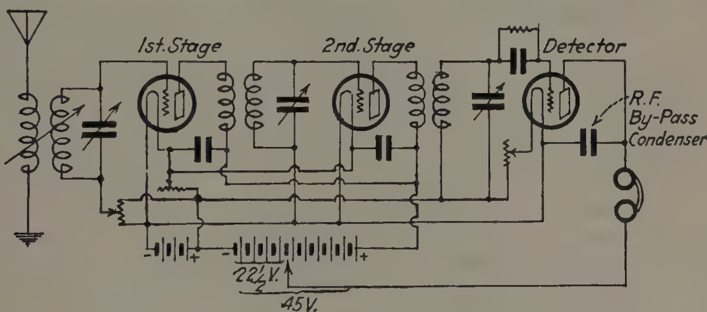


FIG. 130*c*.—Tuned radio frequency circuit.

Radio frequency current flows in the antenna circuit at a frequency corresponding to that at the transmitting station, and, as has been previously mentioned, tuning this circuit increases the current strength usually so little that it may be dispensed with. This is because of the antenna resistance. The secondary circuit should, of course, be tuned, and the lower its resistance the sharper it will tune. Current having a frequency of the antenna current then flows in this circuit and an alternating voltage of the same frequency is, therefore, applied to the grid of the first tube. This causes a radio frequency variation of plate current which induces a voltage in the secondary coil coupled to the plate circuit. Since this secondary circuit is tuned to resonance, the current will be a maximum but will have the same frequency as the plate-current variations, and an alternating voltage of the same frequency is applied to the grid of the second tube. This voltage is considerably greater than the

voltage applied to the grid of the first tube. The reasons are these: first, when an alternating voltage is applied to the grid of any vacuum tube, this voltage causes greater plate current variations than if it were applied in the plate circuit itself. It explains why a vacuum tube amplifies. The plate-current variations may easily be four times as great when the alternating voltage is applied to the grid instead of the plate of the tube. In addition, something exists here which is not possible with untuned transformers. This is a voltage step-up from the plate circuit to the secondary, and this stepped-up voltage is applied to the grid of the second tube. For these same reasons the alternating voltage applied to the grid of the detector tube is greater than that applied either to the first or the second grid. The grid condenser and leak cause a good detecting or rectifying action. The high-frequency alternating voltage which has been amplified is, of course, varying at an audible frequency rate and at the same time. That is, the magnitude of the high-frequency alternating voltage varies at the slower, audible frequency rate which depends upon the sounds entering the transmitter at the transmitting station. The plate-current variations in the detector circuit must then also be at the high-frequency rate. These can be considered as currents of two frequencies of pulsation at the same time. The audible frequency pulsations pass through the head telephones to operate their diaphragms and cause a reproduction of the sounds entering the transmitter, while the radio frequencies are *by passed* by the by-pass condenser.

Questions

1. Define the term "rectification."
2. Describe the action of a vacuum tube with a grid condenser and grid leak connected to an inductively coupled tuner.
3. Draw a graph of a tube as a detector (characteristic curve).
4. How are the rectified signals amplified at audio frequencies?
5. Draw a diagram of a detector and one stage of audio frequency amplification.
6. Describe the regenerative action of a tube.
7. Draw a circuit diagram illustrating regenerative amplification.
8. What are two other amplification systems? Give diagrams.
9. Describe a heterodyne system.
10. Draw a diagram of a radio frequency amplifying system.

CHAPTER XIX

THE VACUUM TUBE AS AN OSCILLATION GENERATOR

Theoretical Action.—The fundamental circuit in Fig. 131 shows a simple vacuum tube oscillator capable of producing waves of a continuous character. The theoretical function of this circuit is applicable to almost every form of tube transmitting circuit and should be carefully analyzed.

The moment the filament switch S is closed and the direct-current generator is running, the filament emits electrons which bombard the plate. A plate current will then flow from P to F

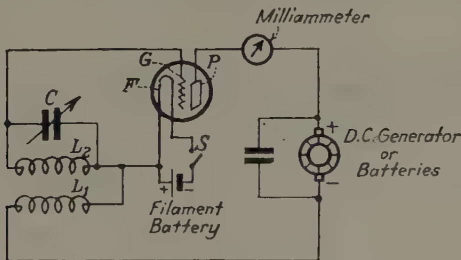


Fig. 131.—Simple vacuum-tube oscillator.

through coil L_1 back to the negative terminal of the generator, completing the circuit and resulting in a steady flow of current in the plate circuit.

This would indicate that a magnetic field must be present about coil L^1. The field would appear to be steady because the flow of plate current is assumed to be constant. The moment the switch S was closed, however, the magnetic field about the coil L^1 expanded, which, according to the electromagnetic law would cut the coil L_2, due to its inductive relation and would, consequently, induce an e.m.f., or difference of potential, across it. If then, the coils are wound in a direction in which L_2 would receive a positive potential at the left-hand end and a negative potential at the right-hand end, the grid which is connected to

the positive end of the coil would receive a positive or + charge. This immediately partly neutralizes the space charge between F and P and allows more current to flow in the plate circuit PFL_1 *Generator.* This results in a greater expansion of the field about L^1 and, consequently, a greater induction into L_2, resulting in a greater charge upon the grid. Again the plate current increases and a heavier charge will again be placed upon the grid. This action will continue up to a certain point, depending upon the characteristics of the tube and the resistance of the circuit.

As soon as the plate current ceases to increase, the potential upon the grid drops to zero. Thus, as the increase made the grid positive by the inductive action of coil L_1 upon L_2, then a sudden decrease in the plate current will result in making the grid negative. Thus, if the positive charge on the grid increases the plate current, it is quite apparent that a negative charge upon the grid will tend to decrease it. The plate current will when the grid is negative decrease to a point below normal just as it will increase above normal when positive. In other words, the plate current will decrease to a certain point in which there will be no further change in the grid potential. Then the complete cycle will be reversed and the operation will be completed all over again. Thus the plate current will rise and fall with a definite frequency, the period of which depends upon the values of the inductance and capacity in the circuit. By using the proper constants, a circuit of this type can be arranged to produce frequencies ranging from the lowest audible range to the highest range in radio frequencies.

In all forms of oscillating systems, especially in which the frequencies are very high, considerable precaution must be taken to keep the resistances of the constants extremely low, otherwise the oscillations are very apt to stop and great difficulty might be encountered in bringing about consistant transmission. These losses, especially at the higher frequencies, are due to the various conditions, *i.e.*, high-frequency resistance losses, dielectric absorption due to poor insulating materials, eddy currents, poor connections, etc.

Oscillating Systems.—There are various arrangements of the capacity and inductance with which oscillations may be generated in accordance with the above fundamental theory. Some of

these systems are employed to a considerable extent in modern tube-transmitting equipment.

Figure 132 illustrates one of the earliest forms of continuous-wave transmitting circuits, known as the Meissner circuit.

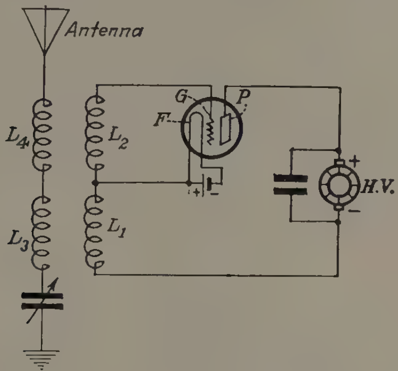


FIG. 132.—Meissner circuit.

All of the various types of circuits will be arranged in a modified form for simplicity. The theoretical function will be the same as in Fig. 131, *i.e.*, coil L_1 will induce an e.m.f. into coil L_2 and, under the conditions set forth in the fundamental circuits, will

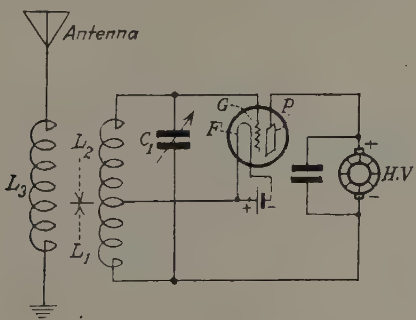


FIG. 133.—Hartley circuit.

produce undamped oscillations at a definite frequency. If the coupling between L_1L_3 and L_2L_4 is carefully adjusted, the alternating e.m.f. present in L_2 will produce an alternating e.m.f. in coil L_3 which will tend to reinforce the original oscillations to a point of considerable increase in amplitude. This reinforcing

action of L_3 upon L_2 will tend to further increase the current in L_1. This building-up process will continue up to a certain point, depending again upon the tube characteristic and the circuit resistance.

It may seem to the beginner that this building-up process takes considerable time but under ordinary conditions it actually takes place in an extremely small fractional part of a second.

Figure 133 illustrates the well-known Hartley circuit. Here the same fundamental conditions of oscillation may be applied. Coil L_1 will induce an e.m.f. into coil L_2 by induction through the

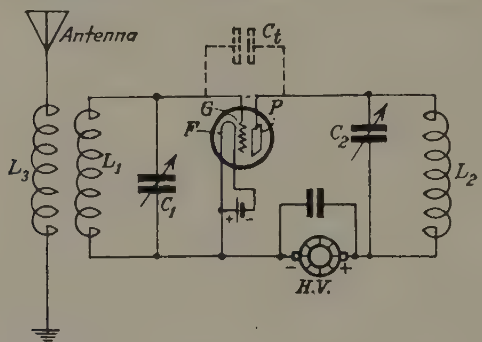


FIG. 134.—Tuned-plate and tuned grid-circuit.

direct coupling of L_1 and L_2. The frequency of the oscillations can then be varied by an increase or decrease in the capacity C_1.

Continuous waves can then be transmitted to the antenna-ground circuit through coil L_3, under conditions of resonance and then radiated from the antenna in the form of continuous electromagnetic waves.

Figure 134 illustrates another well-known system known as the tuned-plate tuned-grid circuit. Oscillation can be produced in the tube without placing L_2 into an inductive relation with L_1 in the following manner:

Assuming a steady plate current flowing in the circuit FPL_2. Consider the inductances L_1 and L_2 to have the same period. Then by adjusting C_1 and C_2 to a value in which the oscillatory constants L_1C_1 equal L_2C_2, thereby adjusting both circuits to a point on or near zero reactance, an e.m.f. will be impressed upon the grid through the tube capacity C_t. This will result in a

reinforcing action upon the grid, which in turn will effect the plate current in a similar manner to the fundamental oscillator in Fig. 131, and consequently, will produce oscillations of a continuous character.

Note.—In all of the other circuits the e.m.f. applied to the grid took place by a form of inductive feed-back. In the tuned-plate system the same action is produced, but by capacitive feed-back.

Figure 135 illustrates the most popular form of a capacitive feed circuit known as the Colpitts system. This system is used in one of the commercial tube transmitters developed by the Radio Corporation of America. This company utilizes the Col-

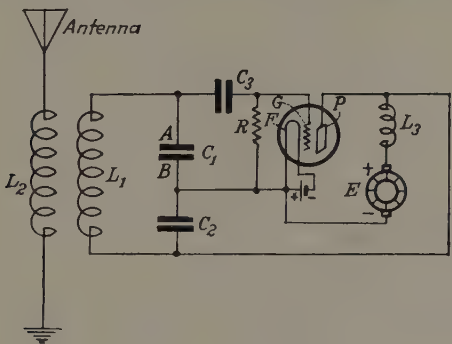


FIG. 135.—Colpitts circuit.

pitts circuit with an alternating e.m.f. upon the plate of the vacuum tube instead of a steady direct-current. This makes the operation much simpler and, therefore, at this time the Colpitts system with direct-current on the plate will be explained.

The oscillating circuit is made up of L_1C_1 and C_2. Assume a steady plate current flowing in circuit $PFEL_3$. This results in a voltage drop across C_2 and incidentally creates a drop of potential across the condenser C_1 at the points A B, which results in the excitation of the grid. Thus by the application of a potential upon the grid by means of the plate and grid excitation condensers C_2 and C_1, respectively, oscillations at a definite frequency are produced by capacity feed-back. The period of these oscillations is controlled by the inductance L_1 and the shunt capacities C_1 and C_2.

When direct current is used for the plate supply in this system there is a possibility of an excessive flow of plate and grid currents which would burn out the tube. To prevent this the condenser C_3 is inserted as a suitable means of insulation against the plate potential terminal applying a heavy positive charge to the grid through the inductance L. Incidentally, C_3, now functioning as a grid condenser, will tend to keep the grid negative, due to its accumulations of electrons while positive. Thus, if the negative charge keeps on accumulating there will eventually result a heavy decrease in the plate current which will stop the tube from oscillating. To insure against this a resistance R of approximately 5,000 ohms is inserted to allow the negative charges to leak off, thus maintaining a steady rise and fall of the radio frequency oscillations.

The choke coil L_3 is inserted to keep the high frequencies from flowing through the generator E.

Questions

1. Draw a diagram of a vacuum-tube oscillator.
2. How does a tube produce continuous oscillations.
3. Name three oscillating systems.
4. Describe the Colpitts system.
5. Describe the Hartley system.

CHAPTER XX

ARC TRANSMITTERS

Discovery of the Arc System.—Because only groups of waves are sent out from a spark type of radio transmitting station, it is not possible to utilize the antenna system to maximum effectiveness, and for many years efforts were made to develop some kind of practical apparatus for generating sustained or undamped high-frequency currents having a suitable frequency for this use. It was not until the use of hydrogen gas in conjunction with a direct-current arc was discovered for the production of high-frequency electrical currents that a simple and reliable means of accomplishing the desired purpose was secured. Since that discovery, the adoption of the arc to the uses of radio telegraph has been universal and widespread, so that today it constitutes one of the most important and satisfactory equipments known to the art. Therefore its importance cannot be overestimated. Arc systems vary in size from the 2-kw. type, used for small stations, to the 500-kw. type, such as are used at the Annapolis Naval Station, and the 1,000-kw. set built by the *United States Navy* at Bordeaux, France.

Comparison of Systems.—Spark transmitters have met with great success in short-range communication at short wave lengths, and with small power, for which requirements they have been particularly adapted. For long-distance communications, however, such as would be required for transcontinental and transoceanic signaling, for example, long wave lengths and high powers are required, which features are essential in order to obtain reliable results during all periods of the day and throughout all seasons of the year. The spark system has been unable to fulfil these requirements for several reasons, among them being difficulties in design and high cost, both of erection and of operation. Another grave difficulty with spark equipment is the interference produced by it with other radio communications,

which interference is caused by an irremovable and inherent characteristic possessed by the spark method—namely, that it creates a broadly tuned radiated wave.

On the other hand, generally speaking, sustained waves, such as are produced by the arc and vacuum-tube systems, are particularly well adapted for long-distance communications, since they are extremely efficient in generating long waves at high powers. The trend of the times, with its demand for more rapid and accurate communications, including ship to shore as well as other communications, has been responsible for the wide adoption of arc radio transmitters throughout the world. The spark system everywhere is now being rapidly displaced in favor of sustained wave equipment.

Elementary Theory of the Arc.—Consider the fundamental circuit illustrated in Fig. 136.

The current flow through an arc is produced by an emission of a vapor stream which is due to the intense heat created almost immediately after the two electrodes have been *struck* and gradually moved apart. This results in a heavy state of ionization in which the positive ions heavily bombard the carbon (cathode) resulting in a *breaking-up* of the molecular structure of the electrode into positive ions and electrons. The electrons (negative particles) then move towards the positive electrode (anode) and form a negative stream of electronic current as long as the generator voltage is maintained at a constant pressure.

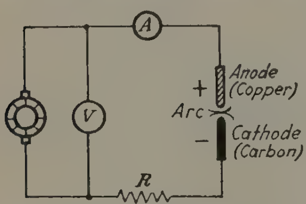


Fig. 136.—Fundamental arc circuit.

Under the conditions set forth, in which a current flows as a result of gas conductivity by ionization due to collision, the resistance of the arc depends entirely on the state of ionization *i.e.*, the greater the ionization the lower will be the resistance. Hence, when applied to an arc under the above conditions, it will be seen that the arc resistance decreases as the current increases. This phenomena is always present in gaseous conducting mediums and should not be confused with the ordinary application of current flow through a non-gaseous conductor.

Thus, if the arc current is increased by decreasing the resistance R the greater will be the ionized vapor, and the greater the ionized vapor, the *fatter* the arc and consequently the lower the arc resistance.

In commercial equipments, the resistance R is known as the arc "ballast" and is absolutely essential for stabilized operation of the arc. This resistance might be short circuited, however, after the arc has been placed in operation as in an oscillatory circuit, and the inductance and inherent resistance will be sufficient to stabilize the arc.

The Oscillating Arc.—If a condenser, in series with an inductance of a fairly high value, as indicated in Fig. 137, is connected across the arc electrodes, an oscillatory current of high-frequency

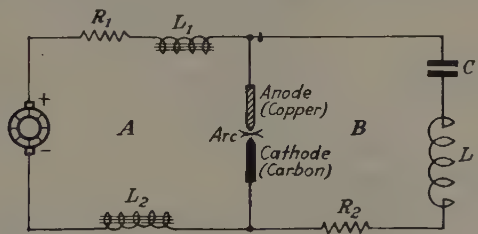


FIG. 137.—Fundamental oscillating arc circuit.

(undamped) oscillations will be produced, its frequency being dependent upon the value of L and C.

Assume circuit B to be opened in order to determine the effect of L_1 and L_2 upon the arc current.

It is extremely important to maintain a steady flow of current through the arc to produce oscillations in circuit B. As soon as the arc is struck therefore, the current across the electrodes will gradually increase. This will result in considerable variation when the oscillatory circuit B is closed. The function of the two inductances L_1 and L_2 is to minimize the variation of current by their self-induction effect which tends to produce a counter e.m.f. resulting in a stabilization of the current flow through the arc. The student will recall that the self-inductance of a circuit will tend to prevent a change in the current. If the inductance value of L_1 and L_2 is very high, therefore, this effect will be accomplished. For this reason, the coils usually connected in

series with arc electrodes have an iron core to introduce a large amount of self-inductance in the circuit.

When the shunt circuit B is closed, a portion of the current charges the condenser and thus reduces the current flowing through the arc. Owing to the rising and falling characteristic of the arc, however, as the current decreases the potential across the arc increases and the condenser continues to charge. When the full charge is reached, the condenser discharges through the arc (coils L_1 and L_2 prevent the discharge from passing through the generator) and momentarily increases the arc current and decreases the potential across it. The charge is then placed upon the opposite plates of the condenser, due to its inertia, and the same action again takes place, resulting in an alternating-current flow of high frequency determined by the constants L and C.

Federal Arc Radio Transmitter.—A federal arc consists of the following main units:

1. A source of direct current of suitable voltage.
2. An arc-converter unit.
3. An antenna-loading inductor.
4. An antenna and ground system.
5. A signaling device.
6. Auxilliary and control apparatus.

The essential features of such a transmitter and its essential electrical circuits are outlined in Fig. 138. The arc converts energy supplied by a direct-current generator into radio frequency energy, causing a flow of sustained high-frequency current in the antenna or radiating circuit. The antenna circuit includes the antenna, the loading inductor, the electrodes of the arc flame, and the ground connection. A choke coil prevents the flow of radio frequency current from the arc back into the power machinery, and serves to sustain and steady the arc flame. The frequency of the sustained current flowing in the antenna circuit depends upon the inductance and capacity of this circuit, therefore, the wave-length may be altered by changing the value of either this inductance or the capacitance, or both. Practically, since the capacity is provided by the antenna and is therefore fixed, the inductance of the circuit is varied in making changes of

wave length. This is accomplished by changing the connections to the antenna-loading inductor.

All parts of the transmitter are stationary except the carbon electrode, which is rotated very slowly by a motor in order that it may burn evenly, and is made so that it may be screwed in and out for the purpose of striking and adjusting the arc. In operation, the length of the arc flame is adjusted in this way to secure

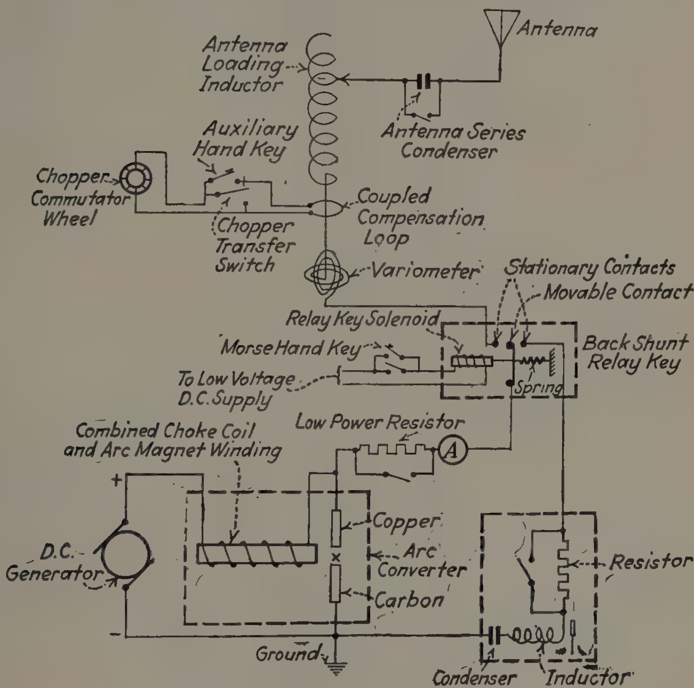


FIG. 138.—"Back-shunt" signaling system.

maximum antenna current. This is the only adjustment required.

After the arc has been properly started, only occasional slight adjustments are needed. The carbon electrode does not burn away as in an ordinary arc, but, on the other hand, usually builds up very slowly, the rate depending upon the chemical composition of the gas in the chamber. This very convenient feature makes it possible to operate this equipment for hours at a time with only a few slight adjustments.

The hydrogen gas in the arc chamber is obtained by decomposition of alcohol, which is fed in, drop by drop, and vaporized by the intense heat of the arc flame. Kerosene may also be used, giving very good operation, particularly on short wave lengths, but has the disadvantage of producing excessively large quantities of soot. Illuminating gas may also be used when available.

Signaling Systems.—While the transmitter is in operation there will be a continuous flow of undamped current in the antenna circuit unless means are provided whereby it may be broken up into the dots and dashes constituting the signals of the telegraphic code. There are four general methods of accomplishing signals as follows:

1. Back-shunt method.
2. Ignition-key method.
3. Compensation method.
4. Chopper method.

Models *K* and *Q* 2-kw. transmitters are equipped with the *back-shunt* method and the Model *X* 2-kw. transmitter with the *ignition-key* method, as the principal means of signaling. The 5-kw. transmitter type CT-1201 is also equipped for signaling by the *ignition-key* method. A compensation system is supplied as an auxiliary means on all these models which are also furnished with choppers for use on short wave lengths when transmitting to stations provided only with detectors intended for receiving damped waves.

Back-shunt Method of Signaling.—The essential units constituting this method of signaling are:

1. The back-shunt circuit.
2. The back-shunt relay key.
3. The Morse hand key.

During operation the arc is switched from the antenna circuit to a local oscillatory circuit by means of a suitable double-contact relay key. The circuits employed for sets equipped with the back-shunt method of signaling are outlined in Fig. 138.

When the movable contact of the back-shunt relay key presses against the stationary contact which is connected to the antenna-loading inductor, the radio frequency current flows in the antenna

circuit. When the movable contact presses against the other stationary contact, the radio frequency current flows in the back-shunt circuit and there is no current in the antenna because it is then disconnected from the arc. The relay key is adjusted so that its movable contact makes connection with one stationary contact before it breaks with the other. This permits the arc

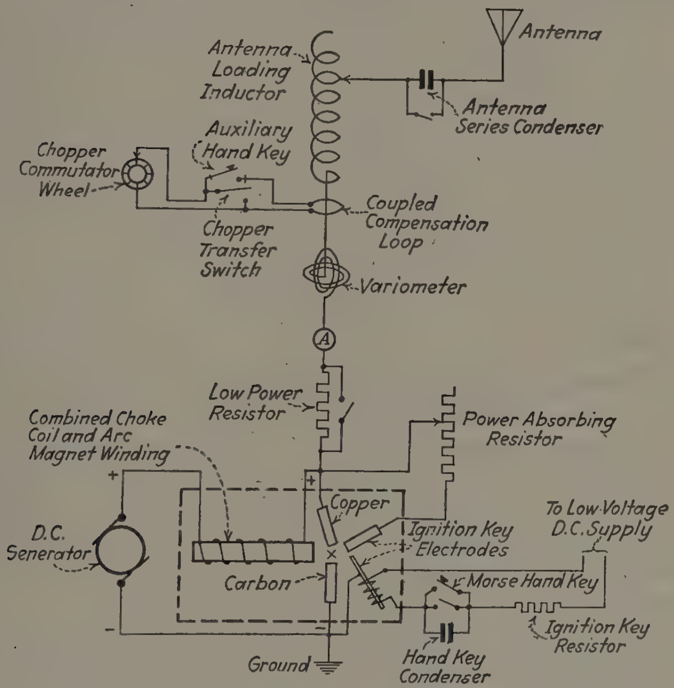


FIG. 139.—"Ignition-key" signaling system.

to remain in constant operation while the current is transferred from the antenna circuit to the back-shunt circuit.

The back-shunt circuit consists of a resister, inductor, and condenser, all connected in series. The resistance of the back-shunt circuit is made variable so that the radio frequency current may remain at the same value whether the arc is operating on the antenna circuit or the back-shunt circuit.

In practice, the back-shunt relay key is operated by an electromagnet, which is in turn controlled by a standard Morse hand

key. When the hand key is depressed, the electromagnet becomes energized and the movable contact of the relay key connects the arc with the antenna circuit. When the hand key is released, a spring causes the movable contact of the relay key to connect the arc with the back-shunt circuit. Current, therefore, flows in the antenna circuit only when the hand key is depressed.

Ignition-key Method of Signaling.—In the *ignition-key* method the arc is extinguished during the periods between the dots and dashes, by shunting it with a resistance. The circuits for the Model *X* 2-kw. transmitter are outlined in Fig. 139.

When the contacts of the ignition key are open, the arc oscillates upon the antenna circuit in the usual manner. When the contacts of the ignition key are closed, the arc becomes shunted by the power-absorbing resistor, which extinguishes it and stops all flow of radio frequency current in the antenna circuit. The ignition-key contacts are located with the arc chamber in close proximity to the electrodes of the arc flame. When the ignition-key contacts are opened, the flash which results is blown by the magnetic field into the gap between the carbon and copper electrodes and the arc flame becomes reignited. Current then flows in the antenna circuit. Signaling is, therefore, accomplished by alternately opening and closing the contacts of the ignition key and thereby alternately igniting and extinguishing the arc flame. Energy is radiated by the antenna at but a single wave-length.

COMPENSATION METHOD OF SIGNALING

A *compensation method* of signaling is furnished with small sets for use in case trouble with the regular signaling system is encountered. In transmitting signals by the compensation method, the length of the radiated wave from the transmitter is caused to vary.

There are two methods of varying the length of the outgoing wave which are in general use. Referring to Fig. 140, the connection for signaling by the *straight compensation* method is shown in full lines in which the auxiliary hand key is connected around a portion of the antenna-loading inductor.

When the auxiliary hand key is depressed, the inductance of the antenna circuit becomes reduced and the length of the

emitted wave, therefore, becomes shortened. Signaling is accomplished by operating the auxiliary hand key and thereby varying the wave length. The receiving station must, of course, tune to receive on the shorter of these two outgoing waves. This shorter wave is called the "signaling" wave.

The dotted lines in Fig. 140 show the *coupled compensation* method of signaling. In this the auxiliary hand key is connected to a loop which is inductively coupled with the antenna-loading inductor rather than being connected directly to it.

When the auxiliary hand key is closed, the loop becomes closed, thereby making a short-circuited turn around the lower part of the antenna-loading inductor. This action decreases the inductance of the antenna circuit by absorption and shortens the length

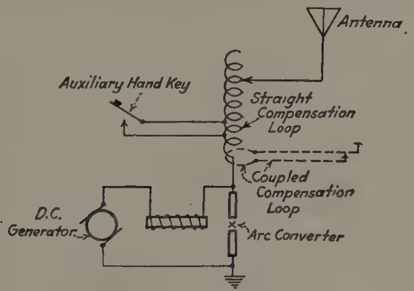


FIG. 140.—Two methods of using the compensating loop system.

of the emitted wave. This is accomplished by introducing mutual inductance between the short-circuited loop and the antenna-loading inductor giving the same result as though connection was made directly in the antenna circuit. It has the advantage that the auxiliary hand key is insulated from the antenna circuit, thereby minimizing danger to the operator, and has the further advantage that sparking at the key contacts is reduced.

Signaling with Chopper.—The frequency of the wave radiated by a Federal arc radio transmitter is very high—much higher than can be heard by the human ear. In transmitting to a station which is receiving with a crystal detector, it is therefore necessary to break up the radiated energy into wave trains of an audible frequency. This is accomplished by the chopper, which consists of a commutator wheel driven by a small motor. There are several methods of connecting the chopper to the antenna

circuit. Referring to Fig. 141, the chopper commutator wheel, when rotated, opens and short-circuits a *coupled compensation* loop at a speed which produces a resultant musical note in the receiver. The radio frequency energy is thus emitted at two wave lengths, as in the case when using the auxiliary hand key, but the wave length rapidly alternates between the maximum and the minimum values. A continuous musical note is thus produced which may be made audible by receivers using crystal detectors.

Another and more recently developed method of connecting the chopper is illustrated in Fig. 141*b*. The chopper commutator wheel and a resistor are connected around a suitable condenser which is placed directly in the antenna circuit. When the bars

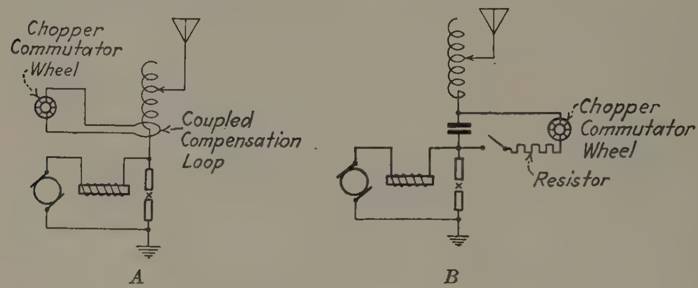


FIG. 141.—Chopper methods of signaling.

of the chopper commutator close, the circuit current flows through the resistor and the arc flame becomes momentarily extinguished. It is immediately reignited as soon as the wheel has rotated a short distance and opened the resistor circuit. This method of signaling, therefore, gives a fully modulated antenna current in wave trains having a musical note. It has the advantage of being less critical to brush resistance than the coupled compensation chopper connection.

With the connections shown in Figs. 141*a* and *b*, signals may be transmitted either by means of the auxiliary hand key connected in series in the circuit between the loop and the chopper or by means of the back-shunt or ignition-key method of signaling. When the auxiliary hand key is used, the radiated wave is broken into wave trains of audible frequency only when the key is closed and the receiver, therefore, gives no audible signal when the key

is open. When the chopper is used with the back-shunt or ignition-key method of signaling, the auxiliary hand key is short-circuited by a small switch. The chopper is then effective whenever current is flowing in the antenna circuit and signaling is accomplished by permitting current to flow in the antenna circuit in accordance with the dots and dashes of the telegraphic code, as described in the paragraphs on the back shunt and ignition-key methods of signaling.

DESCRIPTION OF AND INSTRUCTIONS FOR OPERATION AND CARE OF AN ARC-CONVERTER UNIT

General.—The 2-kw. arc-converter unit is built in two models, which are exactly alike, except for the addition of two auxiliary electrodes for the ignition key, which are supplied with the Model *X* 2-kw. transmitter. The arc converter units for the Models *K* and *Q* transmitters which have no ignition key will be the only types described as they are the types most commonly used on shipboard.

Two-kilowatt Arc-converter Unit, Back-shunt Type, Models K and Q.—The standard 2-kw. arc-converter unit, as used with transmitters having the back-shunt method of signaling, is designed to deliver 5½ amp. to the antenna circuit when operated continuously for a period of 5 hr. It will deliver 7 amp. for a period of 2 hr. and a maximum of 8 amp. for short overloads.

The main parts of the arc-converter unit are:

Chamber.
Magnet poles and magnetic circuit.
Field coils.
Anode, or positive electrode (copper).
Cathode, or negative electrode (carbon)
Alcohol cups.
Exhaust receiver.

Chamber.—In the 2-kw. unit, the arc chamber is made in two sections with the upper half hinged so that it may be swung back and the entire interior exposed for inspection and cleaning.

The top and bottom plates of the chamber are made of bronze, and are water cooled. The center section of the chamber consists of a cast-iron ring which is not water cooled, as it is far enough from the arc flame not to require it. The bronze cooling

plates of the chamber are cast in two parts, which are bolted together with gaskets to provide water-tight joints. The lower water-cooled bronze plate is bolted directly to the cast-iron chamber ring while the upper water-cooled plate rests on the ring with a gasket to make an air-tight joint, and is attached directly to the hinged upper section of the arc. This construction of the chamber insures uniform water-tight castings throughout and makes it possible to repair any leaks which might possibly develop.

Magnetic Circuit.—The 2-kw. unit has a closed magnetic circuit. In other words, the path through which the magnetic flux travels is made entirely of iron, except for the air gap between the magnet poles. One pole projects into the lower half of the arc chamber and the other pole projects into the upper half of the chamber.

The electrodes of the arc are located in the air gap between the two magnet poles, in a manner which subjects the arc flame to a very strong transverse magnetic field. The steel shield, which surrounds the field coils of the arc, provides a closed return path for the magnetic flux. This construction insures a magnetic circuit which has very little leakage flux. This feature is very desirable in order to prevent any influence upon the ship's magnetic compass, even should the arc-converter unit be installed in close proximity thereto.

Field Coils.—The field winding of the 2-kw. unit is constituted of four form-wound coils, three of which are placed in the lower half of the chamber casing and one of which is placed in the upper hinged half. These coils are wound with square copper wire which has both an asbestos and a cotton covering, and will, therefore, stand heavy current. The four coils are exactly alike and are assembled in the arc-converter unit, as shown in Fig. 142. Each has a micanite insulating ring on one side only. The unit is assembled so that this ring provides the necessary insulation between the inner portion of the coils and the grounded frame of the arc. In case the arc-converter unit should ever be disassembled, the greatest care should be taken in reassembling it, to make certain that all the field coils are replaced in the proper manner, with the insulating rings located as shown in the figure.

Each field coil has two terminals on its outer surface and when these are connected, as shown in Fig. 142, the current flows through all the turns in the same direction. Care must be taken always to have these connections properly made, in order that the full magnetic field strength of the arc may be developed. In case one of the coils should be connected so that current flows through it in the wrong direction, only about one-half normal field strength would be obtained and the efficiency of the unit would be greatly impaired. These field coils are insulated from one another and from the frame of the arc by means of micanite and fiber discs. The proper assembling of all these insulating parts is of the greatest importance.

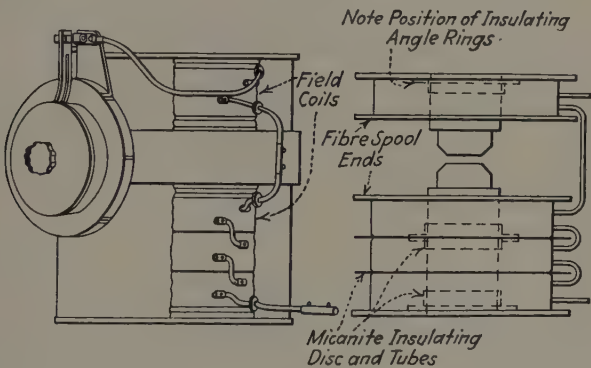


FIG. 142.—Diagram of Federal 2 kw. arc converter unit, showing position of field coils and connections.

The field coils perform a dual function in the circuit; First, they act as choke coils preventing any kick-backs of high-frequency oscillating currents from the arc proper into the generator, which might burn the latter out; second, they provide a magnetic field across the arc, resulting in its steady burning. They also tend to increase the potential difference between the arc electrodes.

Anode.—The anode constitutes the positive electrode of the arc-converter unit. It consists of a water-cooled copper tip, supported by a suitable holder which is insulated from the arc chamber by means of a bakelite disc. This copper tip is brazed to a short piece of brass tubing and this unit, which is known as the *anode tip*, is renewable when it becomes worn after a long

period of operation. The tip is cooled by water, which is forced through a small brass tube inside the main outer tube of the anode holder. A small gasket serves to make a water-tight joint between the anode tip and the anode holder. This tip is fastened in place on the holder by means of a steel nut. It is important that this joint be kept tight, so that the interior of the chamber may be free from water, the presence of which causes the arc flame to become unsteady, thereby giving poor signals.

A proper circulation of water is of great importance in operation, as the tip may be melted by the intense heat of the arc flame if insufficiently cooled.

The anode holder is provided with two hose nipples, one for the inlet and the other for the outlet of the cooling water. A blade projects on the upper side of the holder and provides a means of making an electrical connection between the anode and a terminal clip which is mounted on a bakelite plate immediately above it. In replacing the anode after inspection, care must be taken to see that good contact is secured between it and this terminal clip.

The anode is insulated from the chamber by means of a bakelite disc, which is held in place by a threaded clamping ring on a bell-like projection on the cast-iron chamber ring. A rubber gasket is provided to shield the inner surface of the bakelite disc from soot, and also to make a gas-tight joint between the disc and the chamber. This gasket, as well as the bakelite disc, must be kept absolutely clean, in order that they may provide good insulation between these parts.

Cathode.—The negative electrode of the arc-converter unit is called the "cathode." It consists of a carbon held in a removable carbon holder. The carbon is clamped in the holder by means of a split taper collar and lock nut.

A special wrench and gage is attached to one side of the chamber for use in clamping the carbon in its holder and securing the proper amount of projecting carbon.

The carbon holder is provided with a molded bakelite knob, by means of which the inner portion of the holder may be screwed in and out, in order to adjust the length of the arc flame during operation. When the carbon holder is in position in the arc-converter unit, it is slowly rotated by means of a worm-gear

mechanism, which transmits motion to the carbon holder through a keyway. By means of these gears the carbon is rotated very slowly in order that it may burn evenly.

The carbon holder is located in proper position by means of a latch. When it is desired to remove the holder, it is merely necessary to push upward on the latch, which releases it and allows it to be withdrawn. The holder is held out against the latch by means of a spring, and may be pushed inward against the force of the spring for striking and starting the arc flame.

The holder should never be removed immediately after operation. Two minutes should be allowed to enable the carbon to cool, as otherwise its red heat will ignite the gaseous mixture formed by the admission of air through the removal of the carbon holder. Although the ignition of these gases and the slight explosion which may result are not very dangerous, it is well to avoid these occurrences by allowing the carbon to cool before removing it. The same precaution of allowing the carbon to cool should also be observed in connection with opening the upper half of the arc chamber. If the chamber is opened before the carbon has had sufficient time to cool, an explosion may occur when the air mixes with the chamber gases. An explosion of this kind may cause injury to the operator and should be avoided.

The worm gears of the carbon-rotating mechanism are located in a brass casing and lubricated by an oil cup on the top side of this casing. A shaft with universal joints is provided for connecting these gears on the arc-converter unit to a set of gears on the water pump. This construction makes it possible to use the motor which drives the water pump, for also rotating the carbon electrode. It, of course, necessitates mounting the water pump on the floor immediately beneath the arc converter unit.

Alcohol Supply.—The hydrocarbon gas, which is necessary for the efficient operation of the arc flame, is supplied through the decomposition of alcohol. The alcohol container, which is mounted on top of the arc-converter unit, is provided with a needle valve and sight feed glass by means of which the flow of alcohol may be adjusted and observed. The alcohol reaches the chamber through a small hole in the upper magnet pole, and drips directly into the region of the arc flame. When it comes in

contact with the flame, it is decomposed and a certain amount of hydrocarbon vapor released.

This hydrocarbon, which is immediately volatilized by the heat of the arc, liberates hydrogen in the arc chamber, and this gas assists in maintaining a steady arc. It also minimizes the oxidation of the metal parts of the arc chamber. It is also possible to use a longer arc gap, thereby obtaining greater consistancy in the wave length and an increased intensity of the oscillations.

Either grain alcohol or denatured alcohol may be used. When the transmitter is first started, after a long period of rest, it is necessary to permit the alcohol to drip rather rapidly into the chamber, but after the arc has been burning for a few minutes, the rate of flow may be reduced to only a few drops per minute, which is sufficient to maintain full antenna current and keep the arc operating smoothly.

Some of the 2-kw. transmitters are provided with an alcohol container having a magnetically controlled valve, which automatically starts and stops the flow of alcohol. Others which do not have this valve must be turned off and on by hand, when the arc is operated. The alcohol should always be turned off when the transmitter is stopped for more than a minute or two, otherwise, the excess alcohol in the chamber will run into the anode bell and collect in front of the anode insulating disc and gasket. This, of course, reduces the insulation of the anode electrode, and may cause it to become partially short-circuited in case a great excess of alcohol accumulates.

Exhaust Receiver.—During the operation of an arc-converter unit, a small amount of alcohol is allowed to drip continuously into the chamber. This results in a continuous generation of small quantities of hydrocarbon gas, and it is, of course, necessary to provide some sort of exhaust opening through which these excess gases may be conducted from the chamber. The 2-kw. arc-converter unit is provided with a hose nipple by means of which a hose connection may be made to a unit known as the exhaust receiver, or pressure regulator.

This exhaust receiver consists of a cast aluminum receptacle in two parts separated by a rubber diaphragm. The larger of these two parts is connected by the hose to the chamber, and receives the exhaust gases therefrom. The smaller part provides

a space within which the rubber diaphragm may pulsate, in order to make up for variations in chamber gas pressure. As the arc flame operates and the volume of gases within the chamber fluctuates, this light rubber diaphragm pulsates back and forth, thus keeping the chamber gases at nearly the same atmospheric pressure at all times. A second hose nipple, having a very small hole, provides an outlet for the excess gases, which are conducted through a second rubber hose to an opening beyond the operating room.

Care of Arc-converter Unit.—During ordinary operation, the only parts which should require attention are the chamber and the electrodes. The chamber must be kept clean, water tight and air tight. A tight chamber is absolutely essential for successful operation. If air is allowed to leak into it through loose joints, the arc flame becomes fussy, noisy, and unsteady. Likewise, water in the chamber will also cause the arc flame to become unsteady. It, furthermore, causes the carbon to wear away rapidly, although, during normal operation, it will tend to build up slowly, rather than wear away. The presence of water in the chamber may be detected through the wearing away of the carbon electrode.

In case the chamber should become flooded, through a burned-out anode tip or other cause, it should be wiped out with a dry cloth before restarting the arc flame. The anode insulating disc and its gaskets must also be removed and dried.

When an anode tip burns out it may be removed by loosening the anode-tip nut with the wrench provided, and a new tip can then be installed. Care must be taken to have the small gasket in good condition, which insures a water-tight joint, and to make certain that this joint is perfectly water tight before putting the anode back into the chamber. This is best accomplished by starting the water pump and allowing it to run for a minute, to determine that no water will drip from the joint.

It is very necessary that the carbon holder and other moving parts of the cathode be carefully and thoroughly cleaned at frequent intervals. The soot, which is deposited by the decomposition of alcohol, causes these moving parts to become more or less gummy and sticky in time, and prevents their easy operation. A careful cleaning will keep these parts in good condition and

prevent this sticking or binding. Proper lubrication of the gears and other moving parts is, of course, absolutely necessary in order to insure their long life and proper functioning.

Should it become necessary to inspect or repair the field coils, they may be reached by removing the steel casing of the arc-converter unit, as shown in Fig. 143. The upper field coil may be reached by removing the top steel plate of the unit. In doing this, it is first necessary to unscrew and remove the alcohol cup which is screwed directly into the upper pole piece. The six

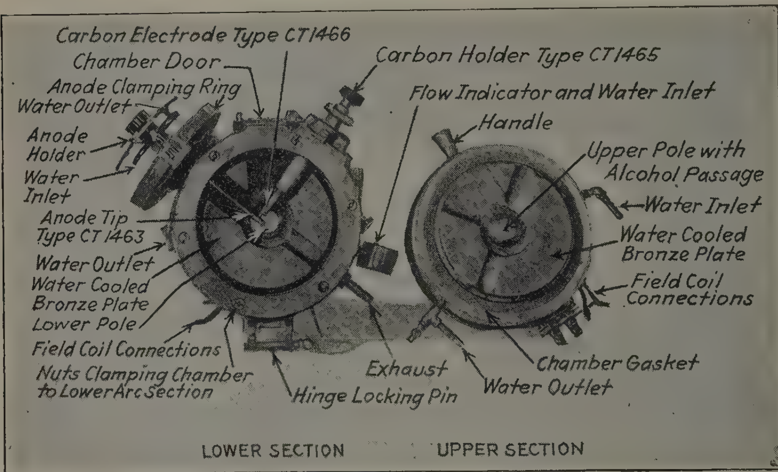


Fig. 143.—Interior of arc chamber.

cap nuts which bolt down the upper plate may then be removed and the plate taken off. The fiber disc and the micanite tube, which insulates this field coil from the frame of the unit, should be carefully removed and inspected to make certain that their insulating qualities have not become impaired. The field-coil connections should be firmly held in the coil terminals by the set screws therein, and should be carefully brought out through the insulating bushings in the steel shell. The main essentials in assembling the field winding are secure connections and proper insulation. The insulating discs and micanite tubes should always be placed as indicated in Fig. 142.

The lower field coils may be reached by removing the upper section of the arc-converter unit, by taking out the hinge pin

and then loosening and removing the six special nuts which fasten down the cast-iron chamber ring. This ring should then be lifted off. The connections to the lower field coils must be disengaged before the steel shell can be taken off. In replacing a burned-out field coil with a spare, or in reassembling the coils after inspection, the greatest care must be taken to replace them in accordance with Fig. 142. In case one of the coils should be connected with its terminals reversed, the magnetic field strength of the arc-converter unit would be greatly reduced and the efficiency of operation impaired. The micanite ring, which is found only on one side of each field coil, serves as a guide in the correct process of reassembling.

In case a water leak should develop in any part of the chamber, the water jacket may be taken apart by removing the screws which bolt it together. This should only be done in case of absolute necessity, as the gasket is almost sure to be damaged by taking it out, and a new one is then required. When this gasket is replaced, varnish or shellac should be used to insure a good joint; and the new gasket material must be of the same thickness as the old material. Such water leaks are not at all likely to occur as all chambers are tested under 100-lb. hot water pressure at the factory, whereas in operation, only a small fraction of this pressure is used. Merely tightening the screws of the water jacket may serve to stop a leak should one occur between the two halves of the jacket.

REMAINING APPARATUS OF 2-KW. FEDERAL ARC RADIO TRANSMITTERS NOT PREVIOUSLY DESCRIBED

In addition to the arc-converter unit, a 2-kw. or 5-kw. transmitter includes the pieces of apparatus described in the following paragraphs:

Antenna Loading Inductor.—This consists of a specially constructed coil connected directly in the antenna circuit, and provides a means whereby any desired wave length within the range of the set can be secured. For short wave lengths only a portion of the inductor is utilized, whereas for long wave lengths more of it is connected.

Wave Lengths of Arc Sets.—Arc transmitters work most efficiently on long wave lengths in the vicinity of 3,000 m. or above.

Wave lengths as high as 18,000 m. are used, but this is not common practice. Arc sets designed for commercial practice on shipboard are tuned to wave lengths, 1,800, 2,100, 2,200, 2,400, and 3,000 m. It is usually the practice on ships equipped with arc sets to call the shore stations on the commercial calling wave of 600 m., using a spark set or operating the arc set on this wave length; using the chopper and then changing over to the higher waves for the transmission of messages.

The inductor is wound with specially designed cable having a very low radio frequency resistance, being composed of many

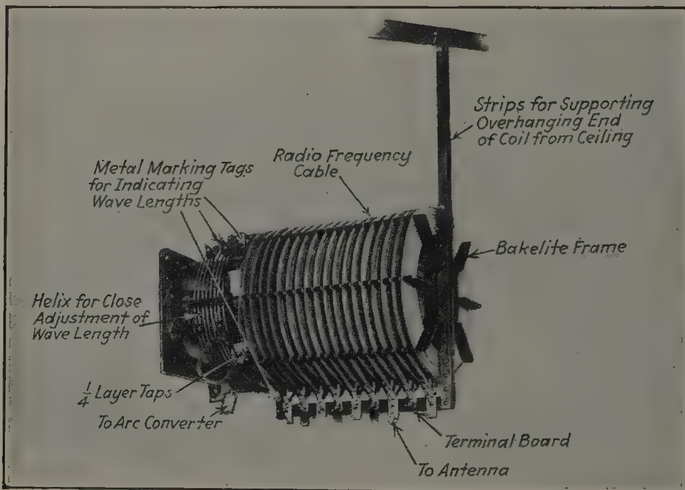


Fig. 144.—Two-kw. antenna-loading inductance.

strands of fine, enameled wire. It is rather heavily insulated, so that it may withstand the high voltages to which it is subjected in service. The cable is wound upon a bakelite frame. Connections are brought out to a terminal board from each layer so as to provide a means of obtaining any desired wave length. Exact adjustments of wave lengths are secured through connection with a bare copper helix placed at the base of the inductor and attached thereto.

When it is desired to tune the transmitter to any particular wave length, the correct number of layers of the inductor must be determined by trial. The antenna is connected to one of the

main terminals of the inductor and the anode terminal is connected to the bare helix. The transmitter is started and the wave length observed by means of a wavemeter. If it is too long, another trial must be made with fewer turns connected in the circuit. If it is too short, a new connection must be made with more of the winding included. Positions will be found for the antenna and arc connections which will give the exact wave length desired.

Arc-control Panel.—This panel constitutes the medium through which connections are made between the arc-converter

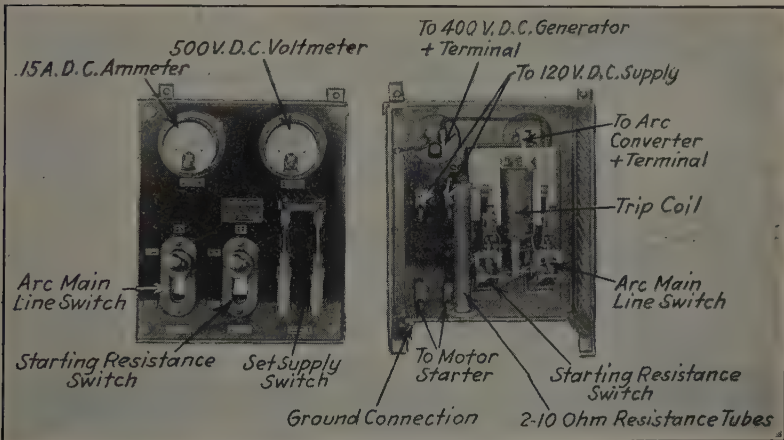


FIG. 145.—Arc-control panel.

unit and the direct-current generator. It also carries a switch through which the entire transmitter is supplied from the 120-volt direct-current source. The following equipment is mounted on this panel:

1 set supply switch with fuses.
1 arc main line switch with overload trip coil.
1 arc starting resistor switch.
1 arc starting resistor.
1 0–15-amp. direct-current ammeter for arc circuit.
1 0–500-volt direct-current voltmeter for arc circuit.

Send-ground-receive Switch.—This provides a means of connecting the antenna either to the transmitter or to the receiver,

or to the ground. A metallic grounded shield is so placed on the receiving clip that, should the switch be operated while power is being delivered to the antenna, energy will not be thrown accidentally into the receiving equipment. Two insulating pillars for the high-voltage parts are made of bakelite and are furnished with shields to prevent corona discharges which would otherwise occur at the high voltages used. A pair of interlock contacts is provided for use in connection with the circuit supplying the water-pump motor, chopper motor, and relay key, which automatically stops these units whenever the switch is thrown to the

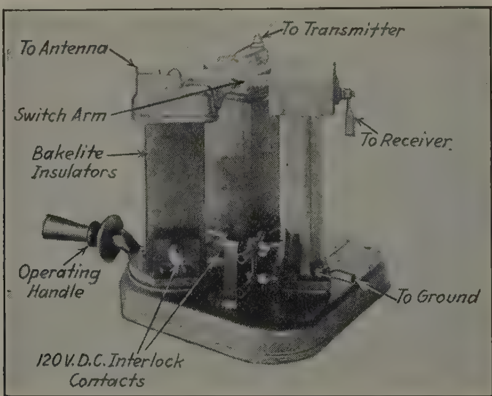


FIG. 146.—Send-ground-receive switch.

receive position, and starts them again when it is thrown to *send*. In transmitters employing the ignition-key system, the generator field coils are also supplied through these interlock contacts. When the switch is thrown to the *receive* position, the generator fields are cut off and the output of the generator reduced practically to nothing. This permits the operator to receive without shutting down the motor generator. In operating a transmitter of ignition-key type, receiving may be accomplished by simply throwing the send-ground-receive switch to the "receive" position, without disturbing any of the other transmitter switches of adjustments. When the switch is thrown back to the *send* position, the generator fields again build up and the arc flame may be restarted by making a few dots with the Morse hand key.

Radio Frequency Ammeter.—This ammeter is mounted on a small panel of insulating material. On the rear of this panel is located a coil having several turns of relatively heavily insulated copper wire, which is connected directly across the terminals of the ammeter. In case the antenna should fall or other short-circuit occur, this coil protects the ammeter from being burned out by direct current. During normal operation, the radio frequency current follows the more direct path through the ammeter, in preference to that through the coil which has a high reactance for such current. This coil, therefore, does not affect the reading of the ammeter for radio frequency currents, although it serves as a protective shunt for direct current.

The 2-kw. radio frequency ammeter is provided with a scale range of 0–10 amp.; however, 8 amp. is the maximum allowable antenna current for the 2-kw. transmitter.

Chopper.—The frequency of the alternating current produced by arc radio transmitters is above the range audible to the

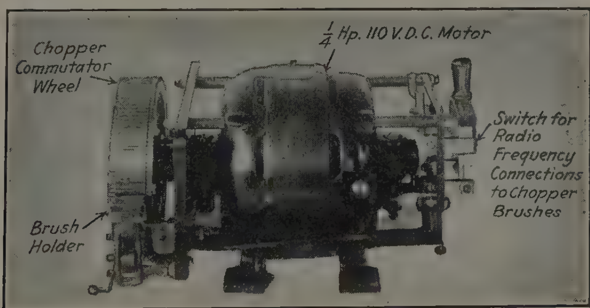


Fig. 147.—Chopper.

human ear. The chopper, therefore, is used on short wave lengths when communicating with a receiving station employing a crystal detector. The chopper breaks up the outgoing wave into a series of wave trains having an audible frequency, and produces a musical note in the telephones at the receiver.

The circuits employed with the chopper are illustrated in Figs. 141*ab*, and are explained in connection with these figures. The commutator wheel is constructed with a portion of the segments connected to a central ring at regular intervals. The remainder of the segments are insulated. During the rotation

of the commutator wheel, the brushes are alternately connected and disconnected through the segments connected to the central ring. The chopper is, therefore, merely a rotary switch, by means of which the circuit to which it is connected may be opened and closed at a rate producing a musical note.

Water Pump.—The 2-kw. transmitter sets have a water pump provided with a set of gears for the carbon rotating mechanism on the arc-converter unit. An adjustable shaft with universal joints serves to make connection between the gears on the pump

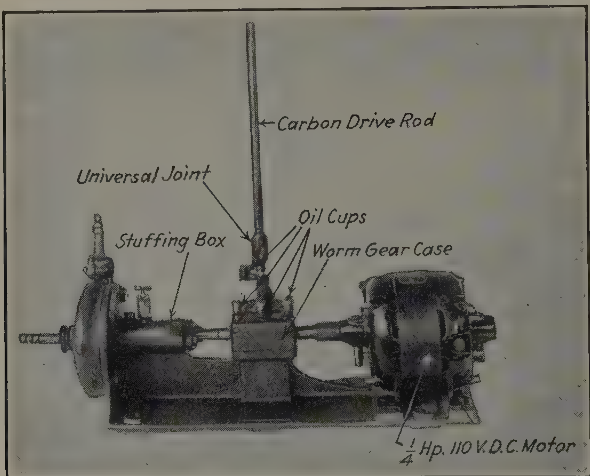


Fig. 148.—Cooling pump for water.

and the gears on the arc-converter unit. A small centrifugal pump of standard construction is utilized.

Water Tank.—A water tank holding 15 gal. of fresh water is supplied with 2-kw. transmitters. Fresh water is necessary so that the anode, which is water cooled, may be insulated from the remainder of the arc-converter unit. Salt water would furnish a conducting path through the anode hose and thereby short-circuit the arc electrodes. Circulation of water is regulated by a valve on the tank.

Water-flow Indicator.—To enable the operator to be certain that water is circulating through the various cooling circuits a flow indicator is provided. The 2-kw. transmitter has this unit mounted directly on the chamber casting. It consists of a small

case having a glass front containing a glass marble within. When water is circulating this marble moves about and rattles.

Antenna Series Condenser.—In operating a transmitter on short wave lengths, it is necessary to place a condenser in series with the antenna circuit. This condenser, which is supplied with all 2-kw. transmitters, consists of a mica condenser mounted within a bakelite tube and fitted with suitable insulating legs. The capacitance of this unit is 0.0006 mf. and it, therefore, considerably reduces the effective capacitance of the antenna circuit. It is connected in series in the antenna circuit on wave lengths below 2,000 m. A switch is provided by means of which it may be short-circuited for wave lengths longer than 2,000 m.

Note-varying Variometer.—The tuning of a transmitter is very sharp and in case a station whose receiver is not exactly tuned is being called the call may not be heard. To enable the operator to vary the length of his outgoing wave slightly while calling a note-varying variometer is supplied with all 2-kw. transmitters. This variometer consists of a moving coil which may be rotated within a stationary coil. When the rotating coil is turned in one direction the outgoing wave length is increased and when it is turned in the opposite direction the wave length is shortened. By rotating the variometer back and forth the operator is enabled slightly to lengthen and shorten his outgoing wave and thereby make the call heard at the receiver.

A notching device built in the variometer handle holds it in a central position, except when it is moved from this position during a call.

The variometer is connected directly in series in the antenna circuit between the antenna-loading inductor and the arc-converter unit. It may be mounted either on a table or on the bulkhead where it is within easy reach of the operator's left hand. This is necessary so that he may turn it while transmitting with his right hand.

Auxiliary Hand Key.—The auxiliary hand key is provided for use with the chopper as an alternative for the usual means of signaling by the back-shunt or ignition-key method. The auxiliary hand key may also be used for signaling on long waves in case of trouble with the regular means. The circuits employed with the auxiliary hand key are shown in Figs. 138 and 139.

The auxiliary hand key is similar to the standard Morse hand key, but is somewhat heavier in construction and is provided with silver contacts ⅝ in. in diameter.

Morse Hand Key.—A standard type of Morse hand key is supplied for controlling the ignition key or back-shunt relay key, depending upon which may be supplied. This key has a short-circuiting switch so that current may be continuously maintained in the antenna circuit if desired.

Condenser for Protecting Hand Key Contacts.—The 2- and 5-kw. transmitters having the "ignition key" method of signaling are provided with a condenser which is shunted around the contacts of the Morse hand key to prevent excessive sparking.

Antenna Low-power Resistor.—To enable the antenna current to be reduced when communicating with a nearby station, and to avoid interference with other traffic, a resistor is supplied, which is connected in series with the antenna circuit. It contains a single resistance unit mounted within a suitable protective casing provided with a switch which, when open, inserts the resistance into the antenna circuit. During normal operation this switch is closed.

Power-absorbing Resistor.—This resistor is shunted around the electrodes of the arc-converter unit during the intervals between dots and dashes, on transmitters having the ignition-key method of signaling. It consists of a number of resistance tubes mounted on suitable framework and protected by side screens. A dial switch mounted on the panel in front of this power-balancing resistor provides a means for varying the value of its resistance. In operation, this resistance should be so adjusted that the direct current supplied to the system remains constant whether operating upon the antenna or upon the resistor. This adjustment is important for securing good signals.

Power-balancing resistors are necessary only with transmitters employing the ignition-key method of signaling.

Back-shunt Relay Key.—This key is fitted to the 2-kw. transmitters provided with the back-shunt method of signaling. It has an insulated movable contact actuated by a pair of solenoids. Two stationary contacts are provided, one on either side of the movable contact. When the electromagnet becomes energized, through the closing of the Morse hand key, the mov-

able contact is pulled over against one of the stationary contacts and the arc-converter unit is connected to the antenna circuit. When the Morse hand key is opened, a spring holds the movable contact against the other stationary contact and connection is made to the local or back-shunt oscillatory circuit. The antenna is then completely disconnected. The two stationary contacts are provided with springs and adjusting screws, so arranged that the movable contact makes connection with one stationary contact before breaking with the other. The arc flame in this manner always has a continuous circuit in which to oscillate.

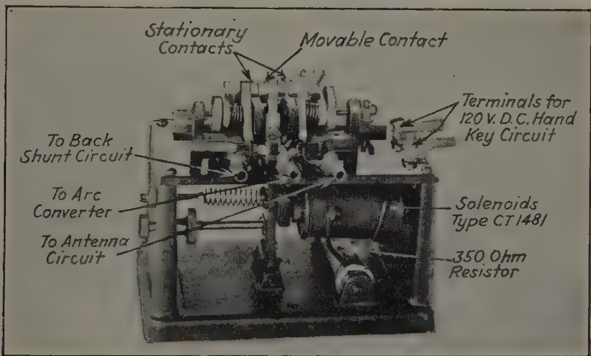


FIG. 149.—Two-kw. "back-shunt" relay key.

A resistance unit of 350 ohms is mounted upon the base of the back-shunt relay key, which is connected in series with its solenoids, thereby insuring a safe current when operated upon a 110 to 120-volt direct-current circuit. The relay key should be adjusted so that its moving contact has about $\frac{1}{32}$ in. motion during the interval in which it is connected to both of the stationary contacts. The opening between the movable contact and the stationary contact when in its extreme position should be approximately $\frac{1}{16}$ in. The springs of the moving contacts should be sufficiently stiff to prevent these contacts from springing back due to the force of the impact of the moving contact. They should not be so stiff, however, as to impair free operation. The spring actuating the moving contact should be adjusted so that the moving element falls nicely when the Morse hand key is operated for rapid hand sending.

Back-shunt Circuit Unit.—This unit consists of an inductor, a condenser, and a resistor, all connected in series. This circuit is shunted around the arc electrodes, during the interval between dots and dashes. The inductor, condenser, and resistor are mounted upon a bakelite panel, forming a self-contained unit.

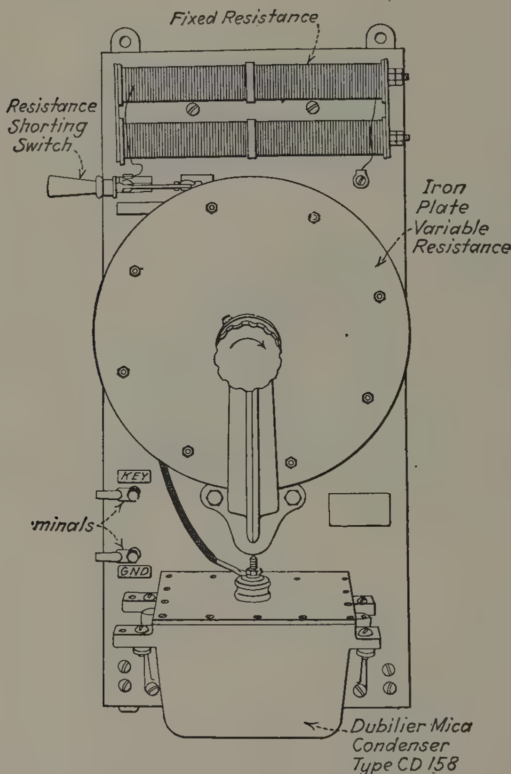


FIG. 150.—Two-kw. "back-shunt" circuit.

The inductor consists of a small coil of wire of suitable dimensions. The condenser is a type CT-158 mica condenser, having a capacitance of 0.004 mf. The two resistance units, which may be shunted by a switch, are mounted at the top of the unit. Additional resistance is inserted in the circuit by placing a steel plate directly in front of the coil. The high-frequency magnetic field

of the coil produces eddy currents and hysteresis losses in this steel plate. When the plate is near the coil, these losses are relatively large and considerable resistance is added to the circuit. When the plate is screwed back, away from the coil by turning the knob provided for this purpose, these losses are reduced and the resistance is correspondingly reduced. The plate, therefore, furnishes a means of making a close adjustment of the resistance of the back-shunt circuit unit. The resistance tubes and the short-circuiting switch, together, provide a means for making a large change in the resistance of the circuit.

In operating the 2-kw. transmitter, the resistance of the back-shunt circuit should be adjusted so that the direct-current input to the equipment is practically constant, whether connected to the antenna circuit or to the local back-shunt circuit. A fairly close adjustment of this resistance is necessary to secure the best signals. The back-shunt circuit is only provided with 2-kw. transmitters having the back-shunt method of signaling.

Two-kilowatt Motor Generator.—The motor generator which is supplied with 2-kw. Federal arc radio transmitters consists of a two-bearing unit, having the armature of the motor and the armature of the generator mounted upon a common shaft. The motor is wound for operation upon a 100 to 120-volt direct-current circuit. The generator is capable of supplying 2 kw. of direct-current power at from 250 to 400 volts. It is shunt wound for separate excitation directly from the 120-volt direct-current source. The maximum rating of the generator is 10 amp. for 2 hr. and the direct current from the generator to the arc-converter unit should never exceed this amount, even though the output is less than 2 kw.

All terminals for both the motor and the generator are located on an inclosed terminal board on top of the machine. Protective devices are mounted inside of the molded insulating case, which covers the terminal board. A diagram of connections is stamped on this molded cover.

Ball bearings are used for the 2-kw. motor generator. These require very little attention other than an occasional filling with suitable grease. Care must be taken to use a good grade of grease containing neither acid nor alkali, as these ingredients will rust the bearings and ultimately destroy them.

Motor-starting Panels.—Federal arc radio transmitters may be provided either with hand-operated or automatic motor-starting panels, or with both. A hand-starting panel is regularly supplied with 2-kw. equipment. This unit is illustrated in Fig. 151. It consists of a standard hand-operated motor-starting switch and a circuit breaker mounted upon a common panel. The circuit breaker serves to protect the motor from short-circuits and overloads. In starting the motor, this circuit breaker is closed first, and then the arm of the starting switch

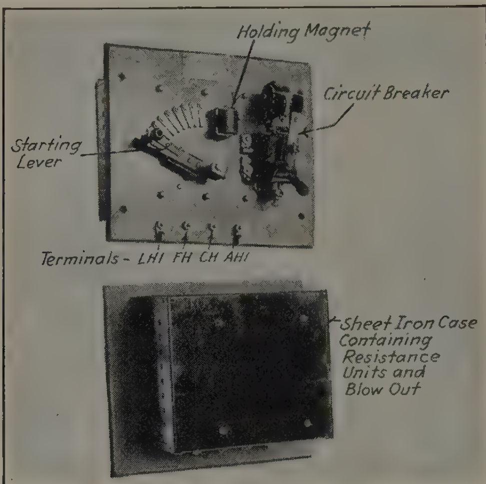


Fig. 151.—Two-kw. motor-starting panel.

is slowly advanced until the motor is brought up to full speed. A small magnet then locks the starting arm in the *on* position. In case the power supply fails, this magnet releases the starting arm, allowing it to return to the *off* position. In shutting down the motor the circuit breaker should always be opened first. An attempt to shut down the motor by releasing the starting arm may result in burning the contacts of the arm. The 2-kw. transmitter may also be shut down by opening the main supply switch on the arc-control panel. This automatically returns the motor-starting arm to the *off* position.

Generator Field Rheostat.—The power output and antenna current of a Federal arc radio transmitter are controlled by adjust-

ing the voltage of the direct-current generator which supplies power to the equipment. For this purpose a generator field rheostat is provided. 2-kw. and 5-kw. motor generators are wound for separate field excitation from the direct-current source supplying the power, and the field rheostat is connected in series between this source of supply and the field coils of the generator.

Land stations having an alternating-current source of power usually have an exciter which is furnished to supply a source of 110 volts direct current for the excitation of the generator field and for the operation of auxiliaries.

In the operation of a 2-kw. transmitter, the generator voltage should be adjusted to secure the desired antenna current. The antenna current must not, however, exceed the rating of this equipment, which is 7 amp. for 2 hr. and 8 amp. for short intervals.

For continuous operation 5½ amp. is the maximum. Likewise, the voltage must not exceed the allowable maximum of 400 volts. When operating on short wave lengths, with a high-resistance antenna, it may not be possible to secure full antenna current, even with 400 volts. This cannot be remedied, as it is due to the increase of antenna resistance on short wave lengths, with a corresponding decrease in efficiency at high frequencies, which latter feature is a characteristic of arc equipment.

The maximum rating for 5-kw. transmitters is 500 volts; and 9 amp. to the antenna is provided for continuous operation. An antenna current of 12 amp. may be safely used for short intervals.

Spare Parts.—The 2-kw. and the 5-kw. transmitters are supplied with spare parts for the motor generator, arc-converter unit and other apparatus.

Figure 152 illustrates the complete assembly of a commercial model "Q" 2-kw. Federal arc, back-shunt system.

Operation of 2-kw. and 5-kw. Federal Arc Radio Transmitters. Before starting a transmitter the following precautions should be taken.

1. Make certain that the water tank is at least three-fourths full of fresh water.
2. Make certain that all the valves of the water-circulating system are open.

3. Start the water pump, and make sure that water is circulating through all the water-cooled parts of the arc-converter unit.

4. Make sure that all moving parts are properly lubricated. Special attention should be given to the bearings of the motor generator.

5. Make sure that there is a supply of alcohol in the alcohol container, and that it feeds properly.

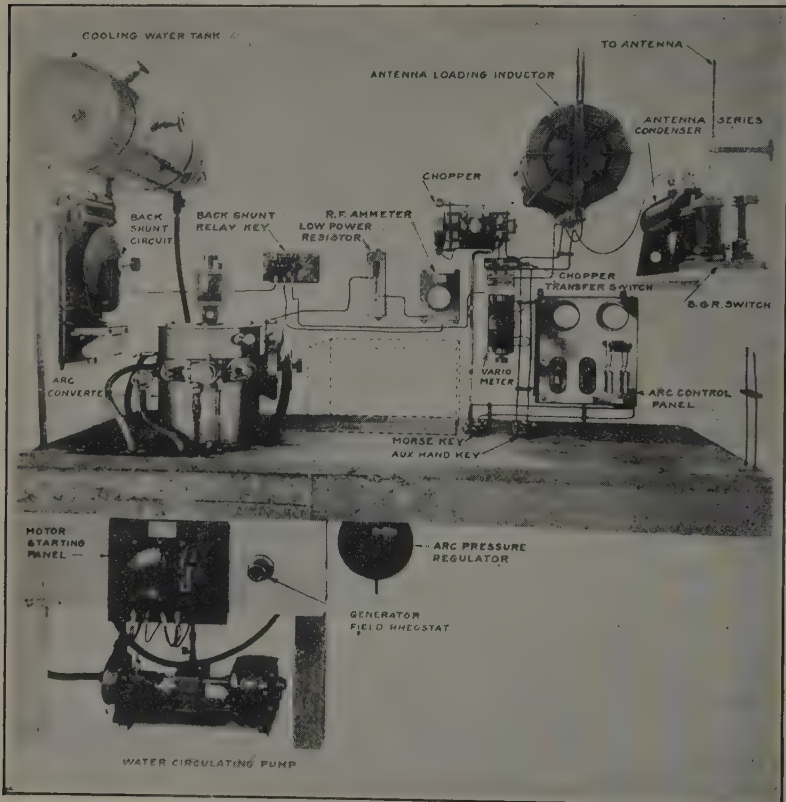


Fig. 152.—Complete arc installation.

Two-kilowatt and Five-kilowatt Federal Arc Radio Transmitters.—All models of 2-kw. and 5-kw. transmitters are alike in operation, with the exception of the signaling system. The models K and Q 2-kw. transmitters have the back-shunt signaling system in which the antenna current is switched from the antenna circuit to a local auxiliary circuit by means of a relay key, which

is in turn controlled by the operator's Morse hand key. The model X 2-kw. transmitter and the type CT-1201, 5-kw. transmitter have the ignition-key signaling system in which the arc flame is extinguished between dots and dashes and reignited each time that a signal is made. The ignition key is controlled by the operator's Morse hand key and there is, therefore, very little difference in the actual motions of operation.

It is occasionally necessary, with all transmitters, to adjust the arc flame to secure maximum antenna current during operation. This is the only attention which is required during sending, but it is important that this attention be given, as the strength and quality of signals is directly dependent upon such proper adjustment. When the equipment is in proper adjustment, a maximum reading of the antenna ammeter is secured. If the arc length is too short the antenna current is reduced, and if the arc length is too great the antenna current is likewise reduced. The adjustment is therefore made by observing the antenna ammeter while turning the adjusting knob on the cathode.

Instructions for starting transmitters equipped with the back-shunt and ignition-key methods of signaling are given here.

To Start a 2-kw. or 5-kw. Federal Arc Radio Transmitter:

1. Close the short-circuit switch on the Morse hand key. In the case of ignition-key transmitters, this action opens the contacts of the ignition key and permits starting of the arc flame as directed below. In the case of transmitters having the back-shunt method of signaling, closing the switch on the Morse hand key will connect the arc converter to the antenna circuit.
2. Close the main supply switch on the arc-control panel. Marked No. I.
3. Place the send-ground-receive switch on *send*. This should start the water pump. Make certain that the water is circulating properly.
4. Start the motor generator by first closing the circuit breaker on the motor-starting panel and then bringing the motor up to speed by slowly advancing the starting arm from the *off* to the *on* position.
5. Adjust the voltage of the generator to about 300 volts by using the generator-field rheostat and observing the voltmeter on the arc-control panel.
6. Start the flow of alcohol, allowing it to drip rather rapidly. If the transmitter is provided with a magnetic alcohol container, the flow of alcohol is automatically started, when the send-ground-receive switch is thrown to *send*. Turn the arc-adjusting knob on the cathode until it has about $\frac{1}{32}$ in. motion when the carbon holder is pushed inward to strike the

arc flame; $\frac{1}{32}$ in. is about the right length of gap to use on starting the arc converter unit, and it is convenient to make sure that this is right, before connecting the circuit to the generator.

7. Close the arc-main-line switch on the arc-control panel by pushing the handle downward until the switch locks close.

8. Strike the arc flame by pushing inward on the arc-adjusting knob. The carbon holder is held out against the stop by a spring inside the cathode. By pushing inward on the carbon holder the force of this spring is overcome and the electrodes are brought together for starting the arc flame. The arc flame should be struck by pushing inward on the carbon holder and quickly allowing it to recede. Too much force should not be used, otherwise the electrodes may become damaged.

It may be necessary to strike the carbon holder several times before the arc is ignited. It may also be necessary to shorten the arc gap by turning the arc-adjusting knob. As soon as the arc flame starts, it should be drawn out slowly and adjusted until oscillations start. When oscillations start, the antenna ammeter will indicate that there is current in the antenna circuit. The arc flame should then be adjusted for a maximum indication of the ammeter.

9. Close the arc-starting resistor switch No. II on the arc control panel by pushing the handle down until it locks. This short-circuits the main arc resistance. Adjust the arc flame for a maximum indication of the antenna ammeter.

10. Signals may now be transmitted by using the Morse hand key. The switch on the key may be left open in case of transmitters having the back-shunt method of signaling, if it is desired to start on the back-shunt circuit rather than on the antenna. This is advisable in order to prevent unnecessary interference.

Caution.—The maximum rating of the 2-kw. transmitter is 7 amp. in the antenna and 10-amp. direct current. The equipment may be operated at 8-amp. antenna current for short periods, but this should never be exceeded, even though the total direct-current input as indicated by the voltmeter and ammeter is less than 2-kw. Excessive current will overheat the radio apparatus and the motor generator and may possibly burn out meters. The 5-kw. transmitter should not be operated in excess of 9-amp. antenna current for continuous operation, or 12-amp. antenna current for intermittent operation, even though the total direct-current input is less than 5-kw.

Use of Ignition Key for Starting.—The Model X 2-kw. transmitters, having the ignition-key method of signaling, and the 5-kw. transmitters, also equipped with the ignition key, lend themselves to the following procedure for restarting the arc

flame shortly after it has been stopped when the chamber is warm:

1. Close the main supply switch.
2. Place the send-ground-receive switch on *send*.
3. Start the motor generator and adjust the voltage to about 250 volts.
4. Start the flow of alcohol.
5. Adjust the carbon holder until there is about $\frac{1}{32}$ in. motion when it is struck.
6. Close the arc main-line switch.
7. Start the arc flame by making dots with the ignition key. If the arc flame does not start immediately the gap should be shortened until it does start. As soon as it starts, adjust for maximum indications of the antenna ammeter.
8. Close the arc-starting resistor switch and adjust the arc flame for the maximum indication of the antenna ammeter.
9. Transmit signals by use of Morse hand key.

After a little practice in starting by means of the ignition key, it is possible to close both the arc main-line switch and the starting-resistor switch before using the key to start the arc flame. This permits the immediate use of full power, thereby minimizing the amount of adjustment and time required for starting up.

TO SHUT DOWN AND RESTART AN IGNITION-KEY TYPE OF TRANSMITTER QUICKLY

Since the arc-converter unit of a transmitter equipped with the ignition-key method of signaling may be restarted by using the ignition key, it is possible to take advantage of this feature when it is desired to stop operation for a few minutes for receiving without stopping the motor generator or the remainder of the equipment.

To stop the arc flame for this purpose, it is merely necessary to leave the Morse hand key open and throw the send-ground-receive switch to *receive*. In the case of the 2-kw. transmitter, this stops the water pump and cuts off the excitation of the direct-current generator, which may be left running. In case of the 5-kw. transmitter, the auxiliaries are stopped and the

generator field is left connected, its output being absorbed in the power-balancing resistor.

To restart the arc flame after receiving, it is merely necessary to throw the send-ground-receive switch to *send* and make a few dots with the ignition key until the arc flame starts. If the duration of the shutdown has been short, and the chamber gases are still warm, the arc flame will reignite immediately. If it has had time to cool off, it may be necessary to slightly shorten the arc gap by turning the arc-adjusting knob. After starting, care should be taken to see that the antenna ammeter indicates full current in the antenna circuit and that the arc flame is in proper adjustment.

Alcohol Supply.—When first starting, the alcohol should be adjusted to drip rapidly. After gas has been generated in the chamber the alcohol flow may be reduced from 10 to 20 drops per minute, to just the sufficient amount to maintain a full antenna current. More than this causes waste and may flood the chamber.

Arc-flame Adjustment.—The importance of keeping the arc flame adjusted to secure a maximum indication of the antenna ammeter has already been pointed out. While transmitting, the operator should glance at the ammeter every few minutes to make certain that the arc flame has not gone out of adjustment. When the electrodes are in good condition, operation for long periods without readjustment may be secured. As has already been pointed out, the antenna current decreases when the arc flame is either too long or too short. When it is too short, the decreases in antenna current are usually accompanied by a characteristic increase in noise inside of the chamber. After some practice, the operator will find it possible to determine whether the arc flame is too long or too short and when it is in proper adjustment by listening to it and simultaneously observing the ammeter.

Power Balance.—The direct-current input to the arc-converter unit should remain constant and should not be affected by making signals. With transmitters having the ignition-key method of signaling, the direct-current power is absorbed by the power-balancing resistor during the intervals between dots and dashes. This latter should be so adjusted that the indication of the direct-current ammeter does not change during signaling. With 2-kw. transmitters, this adjustment is accomplished by a knob on

the power-balancing resistor. This knob may be turned to the right or left until the indication of the direct-current ammeter is the same when the Morse hand key is up as it is when it is depressed. With 5-kw. transmitters, the power-balancing resistor contains a series of taps, and a permanent connection for each wave length is made on the wave changer. If the transmitter has been properly adjusted at the time of its installation, the proper power balance will always be automatically secured for each wave length. Should the power not be balanced, the connections between the wave changer and the power-balancing resistor should be moved to another tap, by either increasing or decreasing the resistance, as may be required.

The 2-kw. transmitters having the back-shunt method of signaling affect power balancing through adjustment of the resistance of the back-shunt circuit. This is accomplished through turning the knob, screwing the steel plate in and out, thereby adjusting its distance from the coil. To decrease the current consumed by the arc-converter unit, when operating on the back-shunt circuit, the steel plate should be screwed in close to the coil. This increases the resistance of the back-shunt circuit. To increase the power absorbed by the back-shunt circuit this plate should be screwed back, away from the coil. Opening and closing the switch, which short-circuits the resistance tube on this unit, serves to produce a fairly large change in the fixed resistance of the back-shunt circuit. By using both this switch and the plate adjustment it is possible to secure a very close balance of power.

To Shut Down the Transmitter.—When it is desired to stop operation for a few minutes without stopping the motor generator, the arc main-line switch should be opened first. This automatically opens the arc-starting resistor switch, which is interlocked with the arc main-line switch. The send-ground-receive switch may then be thrown to the *receive* position. This automatically stops the water pump and, in case a magnetically operated alcohol container is supplied, also shuts off the flow of alcohol. If such a container is not used, the alcohol should be shut off by hand if the shutdown period is to extend beyond a minute or two.

The transmitter may be restarted by throwing the send-ground-receive switch to *send*, closing the arc main-line switch,

striking and adjusting the arc flame, and then closing the arc-starting resistor switch, finally adjusting the arc flame for maximum antenna current.

In case it is desired completely to stop the equipment, the arc main-line switch should be opened first, then the main supply switch, and finally, the send-ground-receive switch should be thrown either to the *receive* or *ground* position. Opening the main-supply switch automatically releases the starter arm of the motor-starting panel. The alcohol should be turned off in case the transmitter is not provided with an automatic alcohol container.

If the transmitter is provided with an ignition key, it is not necessary to open the arc-line switch when stopping for a short period. Throwing the send-ground-receive switch to *receive* is sufficient. On throwing this switch back to *send* the ignition key may be used for reigniting the arc flame.

To Use the Chopper with the Ignition-key or Back-shunt Method of Signaling.—When it is desired to transmit signals on wave lengths shorter than 1,000 m. by means of the chopper, the following procedure should be observed:

1. Throw the chopper transfer switch to the position designated by the name plate.
2. Start the chopper motor by closing the snap switch. This is not necessary with transmitter having a switch which automatically starts the motor when thrown to connect the chopper in the antenna circuit.
3. Start the motor generator and arc-converter unit in the usual manner.
4. Signals may now be transmitted by using the Morse hand key in the usual manner. The circuits are illustrated in Figs. 138 and 139.

To Use the Chopper with the Auxiliary Hand Key.—When it is desired to use the auxiliary hand key in connection with the chopper in place of the regular means of signaling, the procedure to be observed is as follows:

1. Close the short-circuiting switch on the Morse hand key, thereby connecting the arc to the antenna.
2. Throw the chopper transfer switch to the position designated by the name plate.
3. Throw the auxiliary hand key transfer switch to the position designated by the name plate.
4. Start the motor generator and the arc-converter unit in the usual manner.

5. Signals may now be transmitted with the chopper by using the auxiliary hand key.

TO USE THE AUXILIARY HAND KEY FOR TRANSMITTING SIGNALS ON LONG WAVE LENGTHS BY USE OF THE COMPENSATION METHOD

In case trouble is encountered with the regular signaling system, signals may be transmitted by using the auxiliary hand key, as follows:

1. Connect to the antenna circuit by closing the Morse hand key, or by making a temporary connection directly to the antenna circuit, in case of trouble with the relay key or the ignition key.
2. Throw the auxiliary hand-key transfer switch to the position indicated by the name plate.
3. Start the motor generator and arc-converter unit in the usual manner.
4. Signals may now be transmitted by the auxiliary hand key, using the coupled-compensation method of signaling, which is illustrated in Fig. 138.

To Change Wave Length:

1. See that the equipment is shut down.
2. Make sure that the arc main-line switch is open.
3. Change the antenna connection on the antenna-loading inductor to the terminal which is marked with the desired wave length.
4. Change the connection to the bare helix, to the position marked with the desired wave length.
5. Close the short-circuiting switch on the antenna-series condenser, in case the wave length is greater than 2,000 m. Open the short-circuiting switch in case the wave length is less than 2,000 m.

To Transmit on Low Power.—When it is desired to reduce the antenna current for transmitting to a nearby station, the resistance of the antenna circuit may be increased by opening the switch on the antenna low-power resistor. With 2-kw. transmitters, only one switch is used. With 5-kw. transmitters four switches are supplied, by means of which the additional resistance may be placed in the antenna circuit in four steps to secure the desired antenna current.

Figure 153 illustrates the complete wiring diagram of the Federal arc type Q 2-kw. back-shunt relay system.

Figure 154 illustrates the complete wiring diagram of the Federal arc type X 2-kw. ignition-key system.

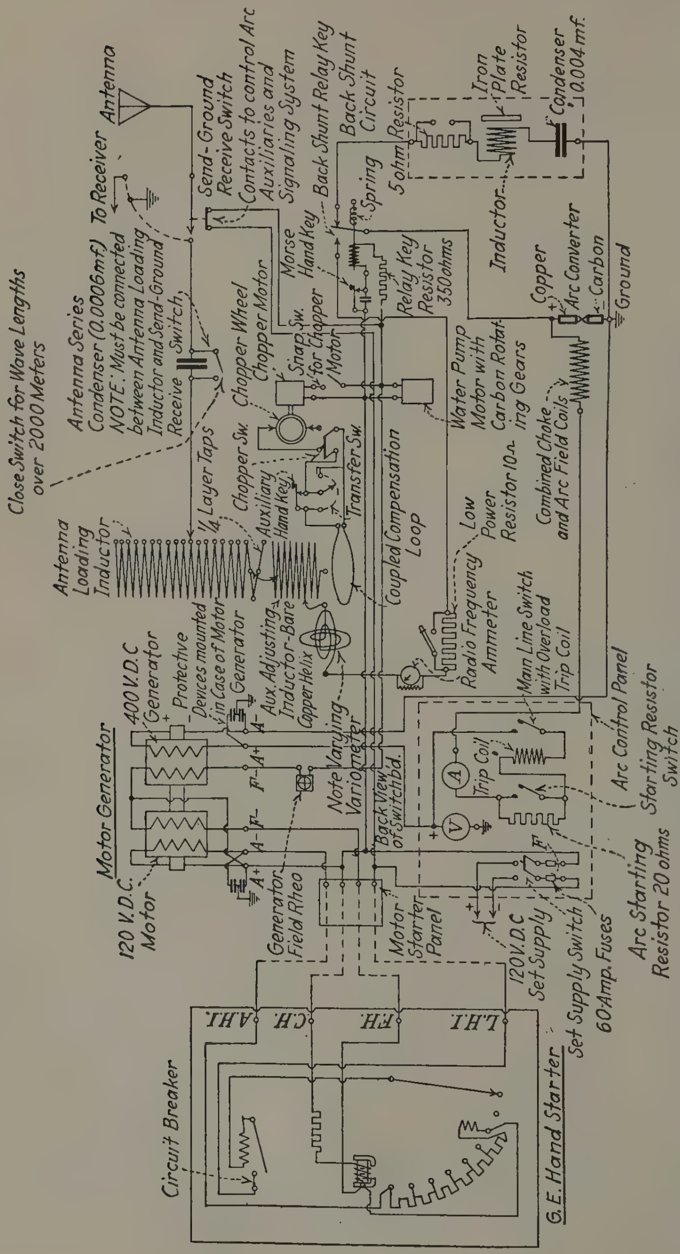


FIG. 153.—Complete Federal arc circuit diagram, type Q.

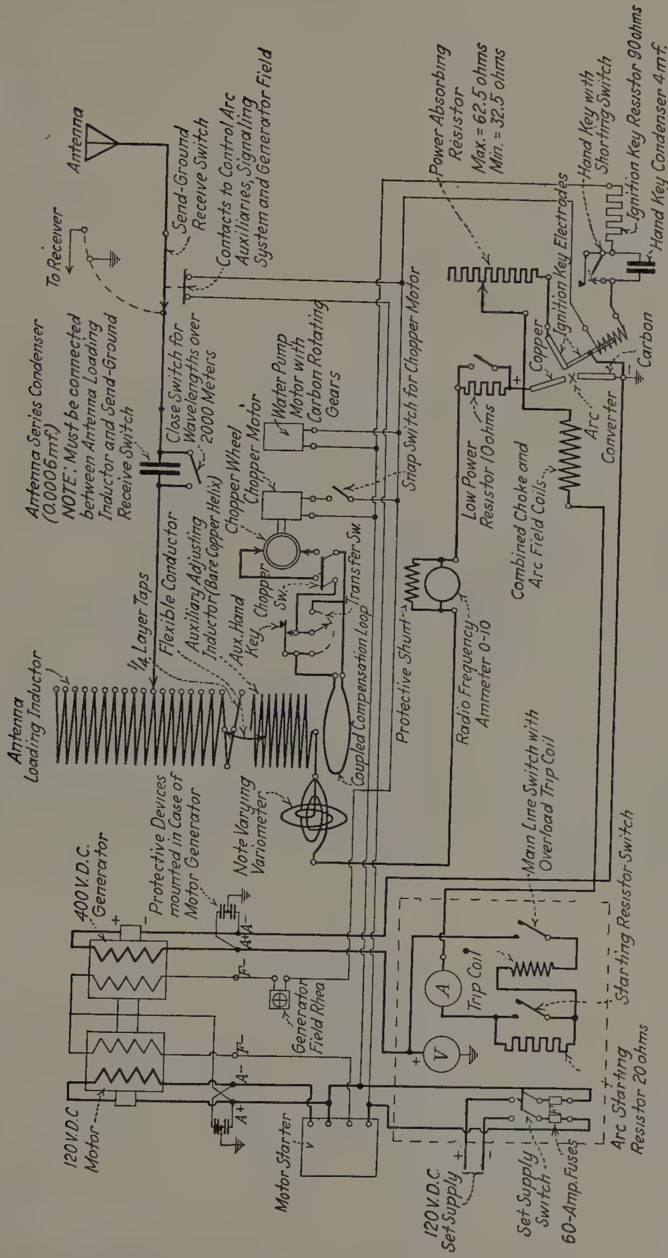


FIG. 154.—Wiring diagram model X 2-kw. Federal Arc ignition key system.

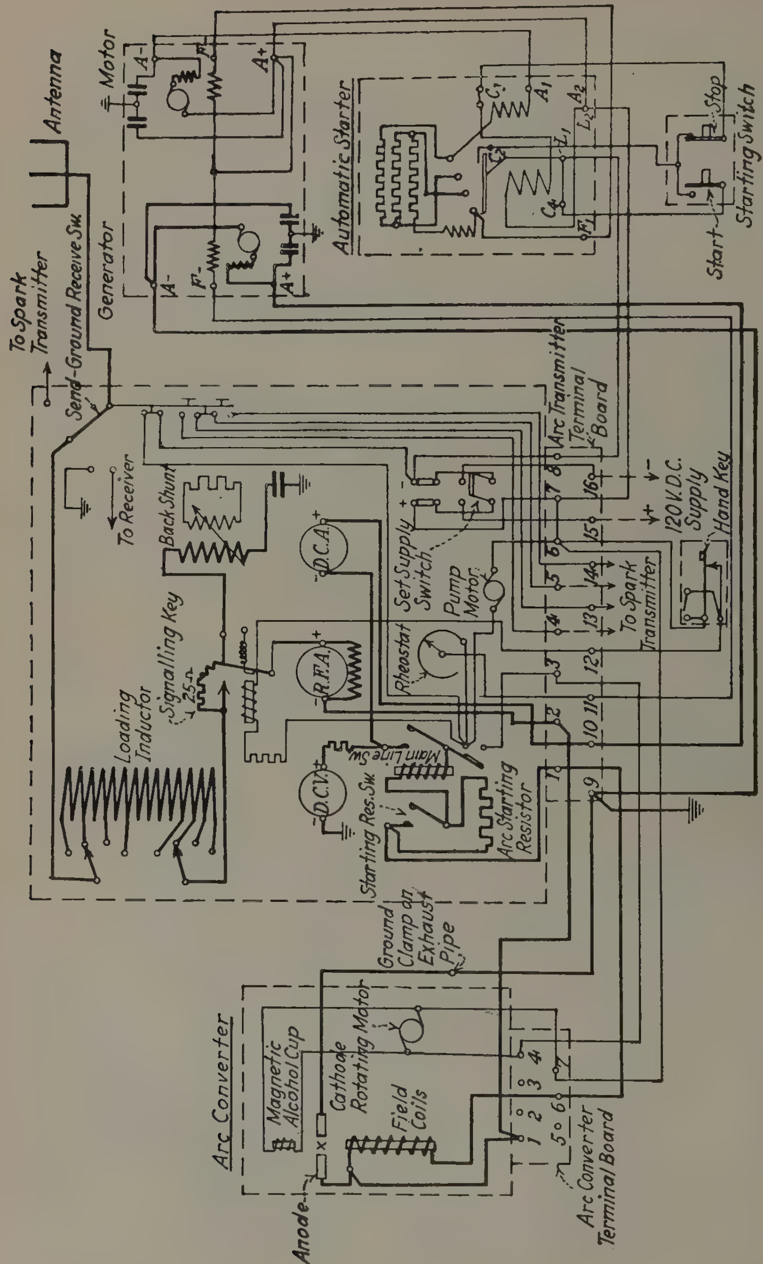


FIG. 155a.—Circuit diagram Federal Arc type 4151.

Figure 155*a* illustrates the complete wiring diagram of the Federal arc type AM 4151. This arc is the same as the back-shunt type with an automatic motor starter and a magnetic alcohol feed system. In addition, the replacement of the carbon by a water cooled copper cathode has resulted in greater stability and clearness of signal.

A typical ship installation of this type is shown in Fig. 155*b*.

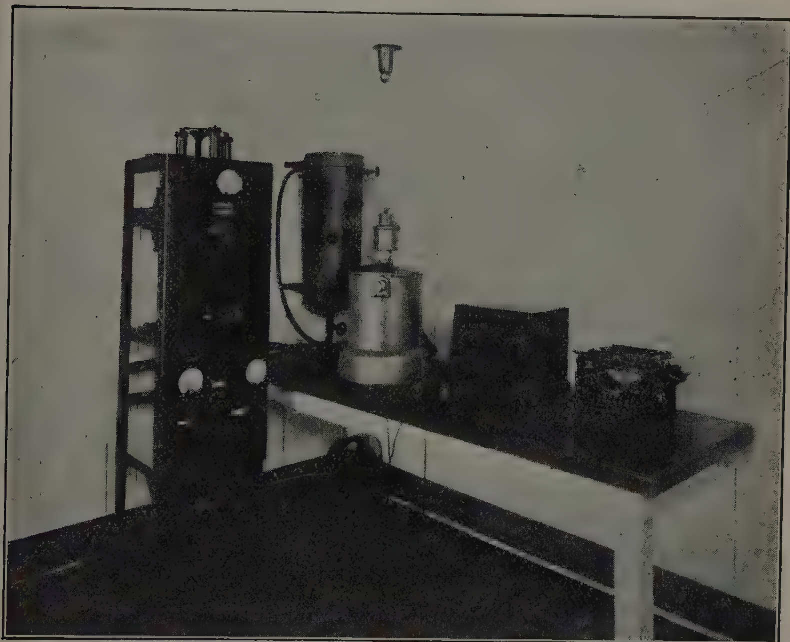


Fig. 155*b*.—Two-kw. Federal Arc transmitter.

INDEPENDENT ARC TRANSMITTER

Explanation of Controlling Apparatus.—The ship's power lines come to switch 21. The only time this switch should be open is when work is to be done on the apparatus, and all current should be disconnected. Switch 22 is in shunt to two contacts on the send-receive switch 10. This switch is normally open. Throwing the switch 10 to send position starts the motor generator 2, and throwing switch 10 to receive position stops the motor generator 2. If it is desired to run motor generator continuously

while receiving, switch 22 should be closed. The motor generator is started automatically by a system consisting of three contactors 28, 29 and 30, which close automatically in order named when the send-receive switch 10 is in send position, or switch 22 is closed.

Switch 23 is in series with two contacts on the send-receive switch 10. When send-receive switch 10 is in send-receive position and arc striking switch 23 closed, the arc-striking circuit is closed, and opening either 10 or 23 opens the circuit. Arc-striking switch 23 is normally closed. Modulator-control switch 24 starts the modulating system and should only be closed when it is necessary to emit damped oscillations, on either 300, 600, or 800 m. Generator-field switch 25 is in series with two contacts on send-receive switch 10 and the generator-field circuit.

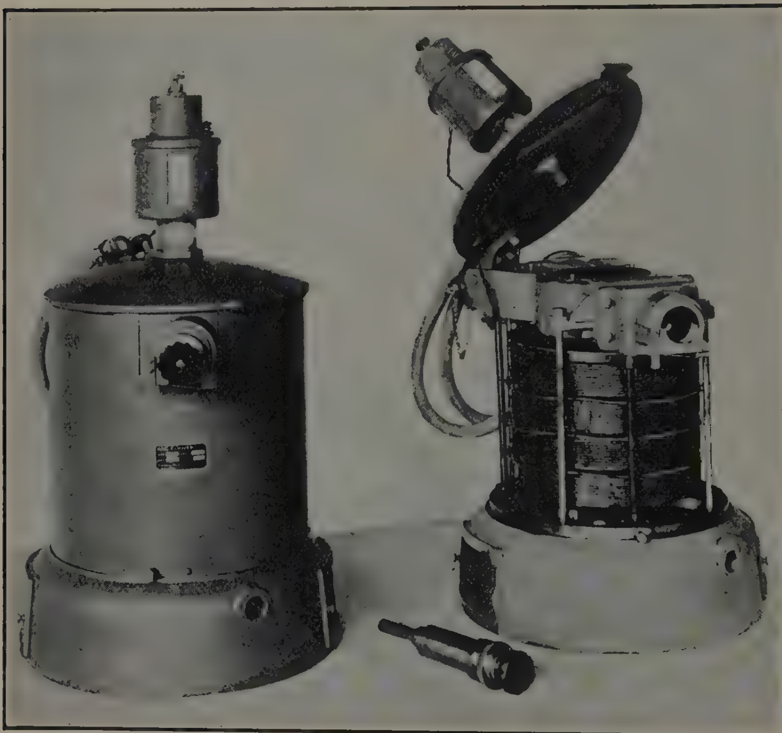


FIG. 155c.—Federal two-kw. arc converter unit type CM 1201.

Simultaneously with the motor-starting operation, current is supplied to the auxiliary motor 51, which drives the water pump for the cooling system and from the opposite end of the same motor shaft a reduction worm and worm-gear operate the carbon-

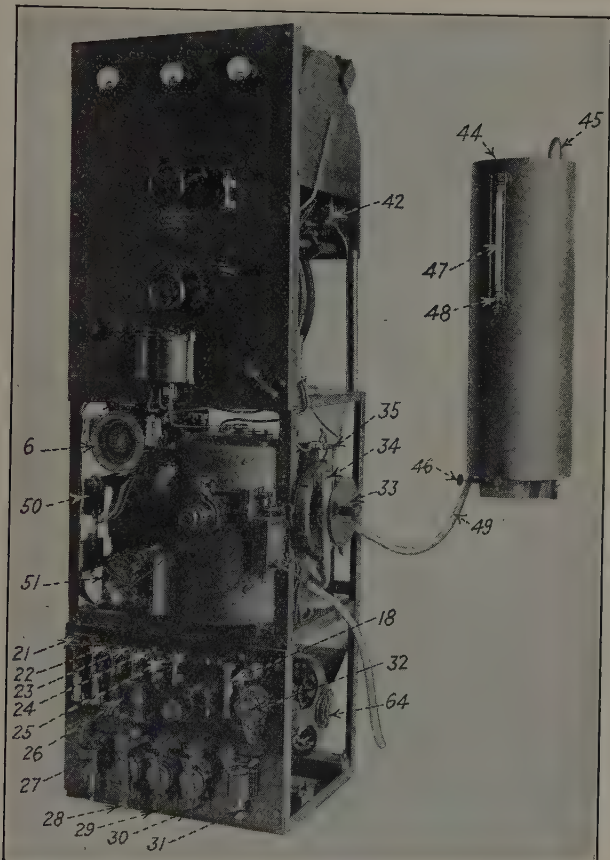


FIG. 156*a*.—Independent arc type RH 1 (panel and right view).

rotating mechanism. It is found necessary to rotate the carbon element of the arc slowly so that it burns off evenly and keeps the oscillating current as steady as practical. Also, simultaneously, the solenoid switch 32 closes and completes the high-voltage circuit, supplying voltage to the arc terminals which have

not been struck. The potential coil of the starting relay 26 is energized, closing the 110-volt supply which actuates the arc-striking solenoid 7. When the arc is struck, the series coil of starting relay 26 is energized because it carries the arc current

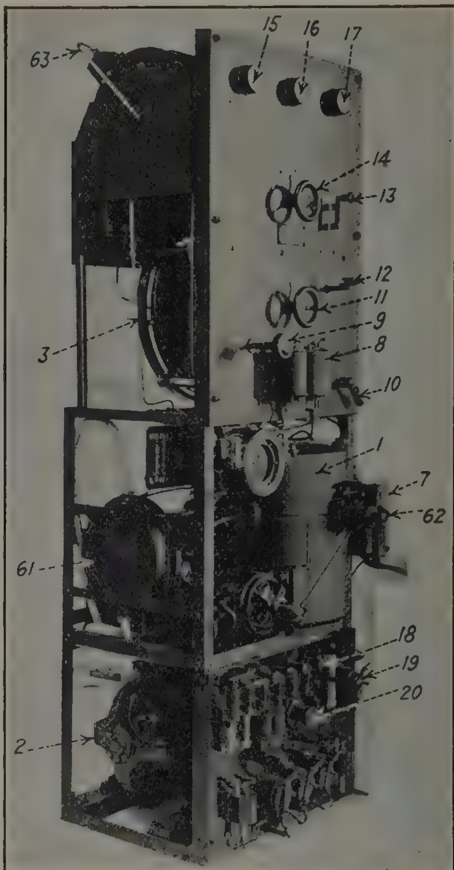


FIG. 156b.—Independent arc type RH 1 (panel and left view).

and it opens the solenoid of 7, the spring of which draws the cathode from the anode. The arc is now established and current flowing through the arc actuating the fuel pot 8, allowing alcohol to drip into the arc chamber. Current flows through the meter 16 which is a 0–15 direct-current ammeter.

Another function of the arc-striking mechanism is to short-circuit the starting resistance 66 when switch 10 is closed. Two overload relays are provided, 27 controlling the low-voltage circuit, and 31 controlling the high-voltage circuit. Each of these

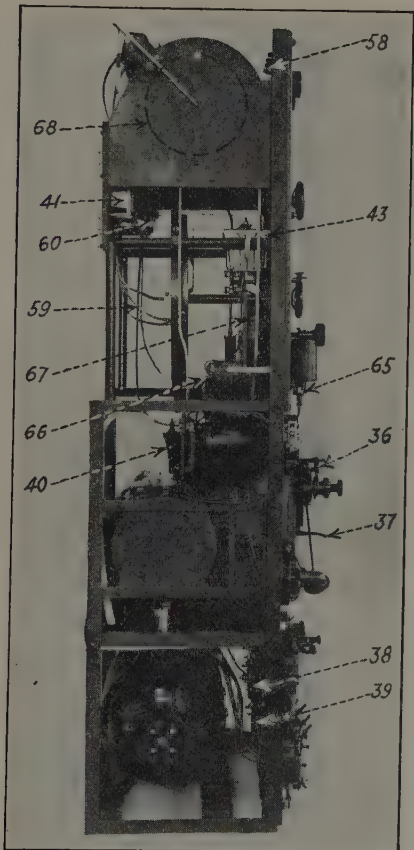


Fig. 156c.—Independent arc type RH 1 (side view).

overload relays have shunt coils which protects against overloads. The action of these is that the series coil operates on the main-line current and, should an overload occur, draws a plunger up which closes the holding-coil circuit, keeping the plunger up. When this occurs it deprives the holding magnets of their current

and the arms are released, falling back. To reset, it is only necessary to open the motor-generator control switch 22 and arc-striking switch 23 for a moment, or throw the send-receive switch 10 to *receive* position, and back again to *send* position.

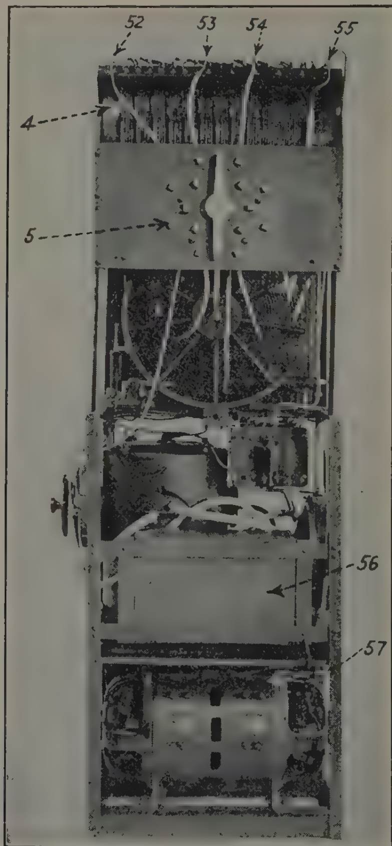


FIG. 156*d*.—Independent arc type RH 1 (rear view).

Number 18 is a 15-amp. fuse in the high-voltage circuit to protect the ammeter and other parts of the circuit in case the current exceeds that amount for any unusual cause.

Rheostat 20 controls the generator-field strength and consequently, the generator-line voltage, and may be adjusted to voltages between approximately 100 and 440 volts.

Radio Frequency Circuit.—The cathode, which is connected to the negative side of the generator line, is grounded. The anode is then connected through the radiation ammeter 17, through the low-power resistor, which is normally shunted by shunting switch 13, through the relay key to the absorbing circuit. When the relay key 12 is in the *down* position the anode is connected to the antenna-loading inductance 4. In the 600, 800, and 2,400 m. positions it will be noted that there is simply an inductance in series with the antenna, the constants of this circuit equalling a frequency that gives the desired wave length. However, on 300 m. an arc will not oscillate steadily with a simple inductance in series with the antenna. Furthermore, the antenna itself has a fundamental wave length of over 300 m., so it is necessary to insert a condenser in series with the antenna. To stabilize the arc, another circuit consisting of an inductance (part of the compensating inductance) and a 0.002-mf. condenser is shunted around the arc to the ground, this circuit having a wave length of 600 m.

There are then two circuits—one of 300 m. running to the antenna, and one of 600 m. running to the ground. The 600-m. circuit is the stabilizer and, as it has a harmonic of 300 m., it feeds energy to the 300-m. circuit which is connected to the antenna.

Absorbing Circuit.—In signaling, the energy, converted by the arc, is diverted either to or from the antenna at a rate corresponding to dots and dashes. In the key-up position, the energy is diverted from the antenna by the relay key to an absorbing circuit, which consists of a 0.004-mf. condenser 43, an inductor, and a combined iron-plate resistor and absorbing resistor 9. The antenna ammeter, 17, is also thrown from the antenna circuit to the absorbing circuit by the relay key, so this meter reads the current in each circuit depending upon the position of the key. The iron-plate resistor should be adjusted so that the direct-current load (meter 16) is nearly constant when sending. If the resistor is improperly adjusted the absorbing circuit will draw more than the radiating circuit, causing the arc to be unsteady, especially on the lower wave lengths.

Modulating System.—This consists of a ¼ hp. direct-current motor directly coupled to a large commutator, 6. Every sixth

bar is connected together, and brushes are located diametrically opposite each other. The two brushes are connected to a loop, 68, of Litzendraht wire, which is in inductive relation to the antenna-loading inductance.

This machine runs at a speed of 1,700 r.p.m. and current is induced in loop 68, at times when it is shorted by the commutator circuit. The speed and number of bars correspond to 1,000 short-circuits a second, or a 500-cycle note approximately. These short-circuits change the wave length appreciably, and reception on a crystal or vacuum tube detector will be of the nature of a 1,000-cycle tone.

Wave-change Switch.—A wave-change switch is provided, which permits transmission on four wave lengths. These positions are marked by number plates and have corresponding ratchet stops. To the right of a wave-length position is an intermediate point which provides connection directly to the rotating contact of the compensating inductance, in order that, after having adjusted the antenna-loading inductance by steps to an approximate value, the proper amount of compensating inductance may be exactly determined in a convenient manner.

This switch also provides for the necessary connections of the additional 600-m. circuit when operating on the 300-m. wave length.

Practical Operation.—Assume now that the electrical connections have been made and all the mechanical work outlined in previous instructions has been complied with.

1. Place send-receive switch 10 in receive position.

2. Close switches, main switch 21, motor-generator control switch 22, arc-striking switch 23, generator-field switch 25, resistance cut-out 19 and lower power resistance shunt switch 13.

3. See that loading coil leads 52, 53, 54, and 55 are approximately in the position shown in the photograph. Also leads 59 running to the compensating inductance, approximately as shown in the photograph.

4. Place wave-change switch 14 in 2,400-m. position.

5. Placing the send-receive switch 10 in *send* position closes circuits which perform the following:

a. Motor generator is brought up to full speed by the closing of main-line contactor 28, and the two contactors of the automatic starter 29 and 30.

b. Simultaneously, the pump and carbon-rotating motor 51 is brought to full speed. The carbon should be rotating slowly and the sight feed on the water circulating will show the red ball, indicating that the pump is working.

c. The main-line contactor 32 has closed, closing the high-potential circuit. The arc-striking relay 26 works, striking the arc electromagnetically through the arc striking mechanism 7. A few seconds after the arc is struck, the arc-starting resistor is shorter. The hydrocarbon supply magnet 8 has operated, supplying alcohol to the arc chamber, which is evaporated and the vapor contains hydrogen which is necessary to maintain a steady arc. Too much alcohol will be indicated by a white vapor rising in the alcohol sight glass; too little by the arc being unsteady.

d. Direct-current voltmeter 15 reads the arc voltage; direct-current ammeter 16 reads the arc current, and radio frequency ammeter 17 the absorbing circuit current, and when the key is pressed down, 17 reads the antenna current.

When throwing send-receive switch 10 to the *send* position, and the arc strikes, it may not ignite upon the first inward thrust of the mechanism. This may be due to excessive spacing between the copper and carbon elements, and the carbon should be adjusted to proper relation to the copper by the cathode adjustment knob 62 which moves the cathode nearer to the copper anode when turned in a counter-clockwise direction.

The arc-striking relay has an automatic action, and when the cathode strikes the anode and returns, if the arc does not ignite, the action is repeated again and again until it does ignite; of course, it should be assisted by adjusting the cathode by knob 62.

Lock the relay key by closing the hand key on the table and measure the wave length being transmitted, making sure on all wave lengths that the antenna circuit and not the absorbing circuit is measured.

Assume that the wave length measured was 3,300 m.; then cut out one or more sections of the antenna-loading inductance and find the wave length to be 2,300 m. The final adjustment would be made by throwing the wave-change switch to the right of the 2,400-m. position and tuning with the compensating inductance until the wave length is exactly 2,400 m., as indicated by the wave meter.

After final adjustment is made by the variable arm on the compensating inductance, the 2,400-m. lead from the lower half of the wave-change switch is brought to the inductance in exactly the same point where the variable contact was. The wave-change switch can then be moved to the other wave-length position and further adjustments made with the antenna-loading inductance and compensating inductance in the same manner.

On 600 m., it is best to place as much of the total inductance required in the antenna-loading inductance and as little as possible in the compensating inductance.

In adjusting the 300-m. wave length, the wave-change switch should be thrown to the 300-m. position and the antenna disconnected by means of the lightning switch. A wave meter should be placed in position near the compensating inductance, which should be adjusted by means of a flexible contact from the auxiliary wave-changer panel, to a wave length of 600 m. Current will not be indicated by the radio frequency ammeter, as this is connected in the antenna circuit. The antenna should then be connected to a sufficient number of the one-turn gaps of the antenna-loading inductance, connected in the antenna circuit, to give a maximum antenna-current indication on the radio frequency ammeter, at a wave length of 300 m. It is necessary that the amount of inductance approximate tuning to 300 m. in order that current will flow in the antenna. Not more than six or eight turns, and generally less, will be required.

The relay key should be kept in good order. When adjusting for the *up* position the lower contacts should be compressed $\frac{1}{16}$ in. with a space of $\frac{1}{32}$ in. between the upper contacts, and the air gap between armature and field poles should be very small. In the *down* position the upper contacts are compressed $\frac{3}{32}$ in. with the lower contacts $\frac{1}{16}$ in. apart.

The commutators of the motor, generator, pump motor, modulator motor, and modulator should be kept clean and smooth, and examination made to see that the brushes are wearing evenly.

The operator should always see that the circulation indication is indicating when the set is in operation. The water tank should be kept full to the level indicated, and the alcohol feed reservoir

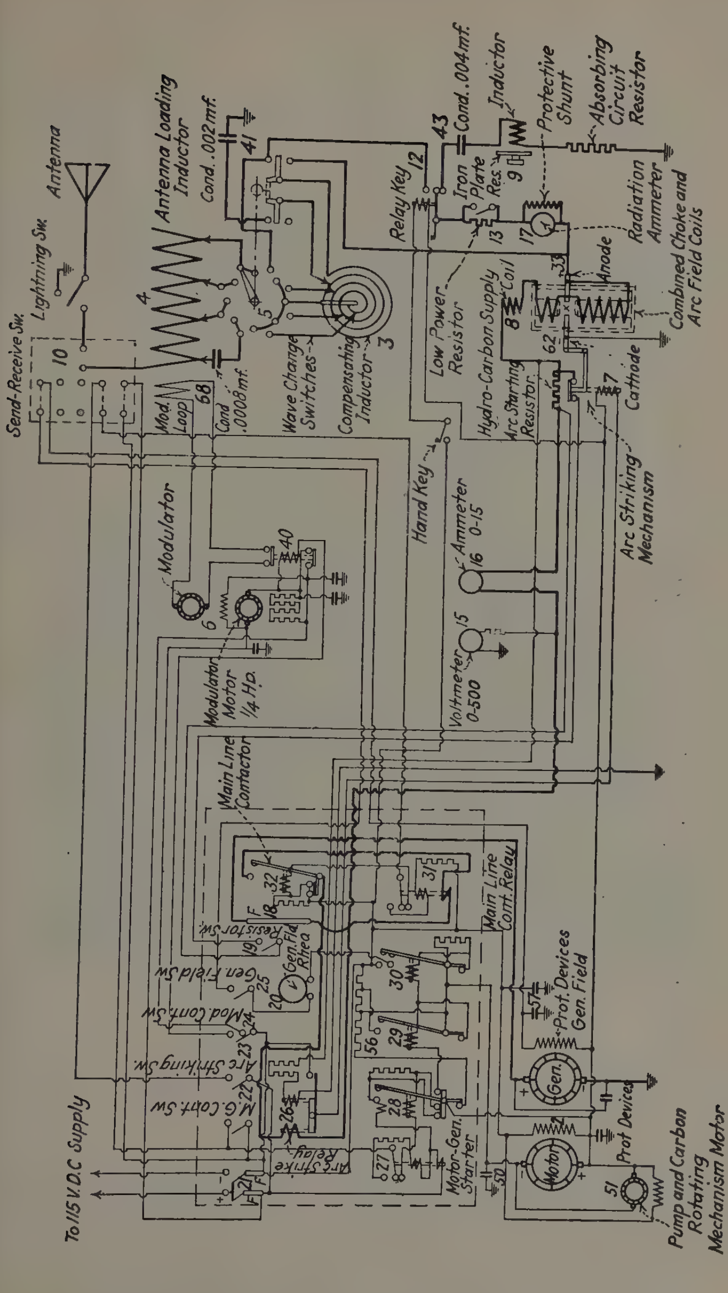


FIG. 157.—Independent arc diagram RH 1.

kept full, as this only holds enough alcohol for 10 hr. of continuous operation.

All moving parts should be properly lubricated and parts making electrical contacts, such as switch blades, contactors, etc., should be kept smooth and clean.

Fig. 158.—Typical shipboard installation, independent arc. S. S. Robert E. Lee.

Every morning the apparatus should be dusted thoroughly with cheesecloth, and at least monthly it should be cleaned with alcohol.

The copper parts should be polished if they are not lacquered.

The use of the 300 meter wave, since the advent of broadcasting, has been discontinued.

Questions

1. How does the arc produce continuous oscillations?
2. What are the positive and negative electrodes composed of?
3. What is the function of the choke coils?
4. Draw a diagram of a simple oscillatory arc.
5. What kind of vapor is emitted between the arc electrodes?
6. What are the main units of the Federal arc transmitter?
7. What are the various signalling systems?
8. How can the continuous waves be broken up into interrupted continuous waves?
9. Why does the negative electrode revolve?
10. Draw a complete diagram of the Federal 2-kw. arc system.
11. Explain how to place the arc into operation.
12. Describe the operation of the back-shunt relay.
13. How would the Independent arc be placed into operation?

CHAPTER XXI

RADIO CORPORATION VACUUM TUBE TRANSMITTERS

Perhaps the greatest step towards the elimination of spark transmission has been accomplished by the Radio Corporation of America in the development of a tube-attachment system which eliminates the spark without necessitating any change in the power and tuning circuits. This is done by inserting a tube rack in place of the quenched and synchronous gaps which were formerly located on the power panel. It is an extremely compact arrangement and an economical change and, therefore, puts the transmitter to which it is attached into the unquestionable tube category, without entailing a complete change in the ship's radio equipment. Such an equipment is shown in Figs. 159, 160, and 161.

The plate power is supplied by the usual 2-kw. transformer, properly controlled by the generator-field regulating devices. The filaments are ignited by a small rotary converter and step-down transformer located at the rear base of the panel. The oscillatory circuits are of the Colpitts type, including a grid and plate excitation condenser with a shunt or *tank* inductance which in turn is coupled to the secondary pancake coil. The tube grid and plate circuits are properly supplied by radio frequency choke coils and by-pass condensers.

To Place into Operation.

1. Close the direct-current switch on the panel and press the starter button.

2. Close the *generator field* S.P.S.T. switch on the panel.

3. Throw the *antenna switch* into the transmitting position. The motor is now gradually brought up to speed by the automatic starter plunger short-circuiting the motor armature, starting resistances. When the bar makes contact with the last finger the generator field is excited and the rotary converter placed into operation.

4. Adjust the *generator field rheostat* to about half-way position.
5. Adjust the *motor field rheostat* to the same position.
6. Close the alternating-current power switch on the panel.

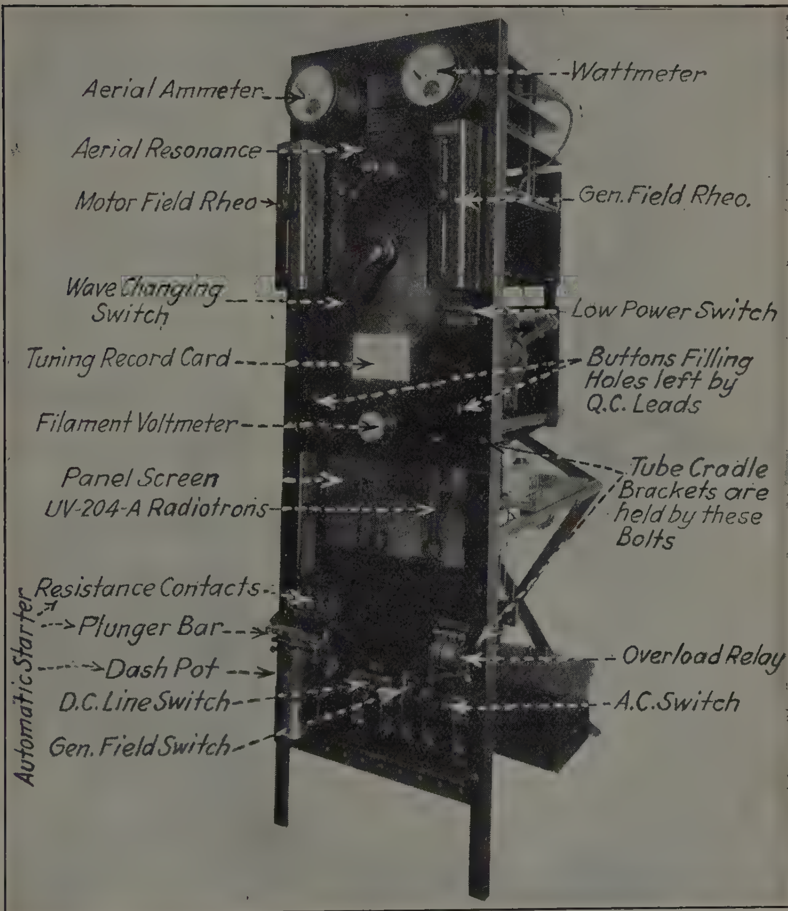


FIG. 159.—P-8 R.C.A. transmitter with tube converter type ET-3628.

7. Adjust the filament voltage between 9 and 10 volts by varying the filament resistance located in the converter circuit. This voltage must *never* exceed 10 volts.

8. Place the *wave length* change-over switch to the desired wave.

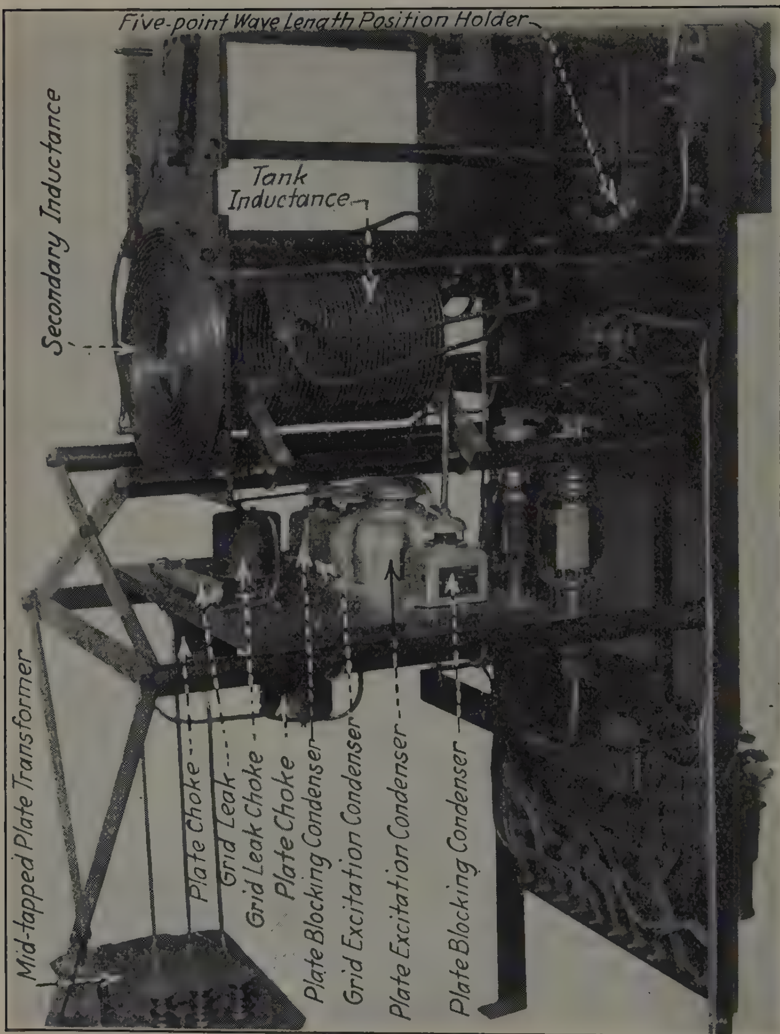


FIG. 160.—P-8 RCA transmitter with tube converter, rear view.

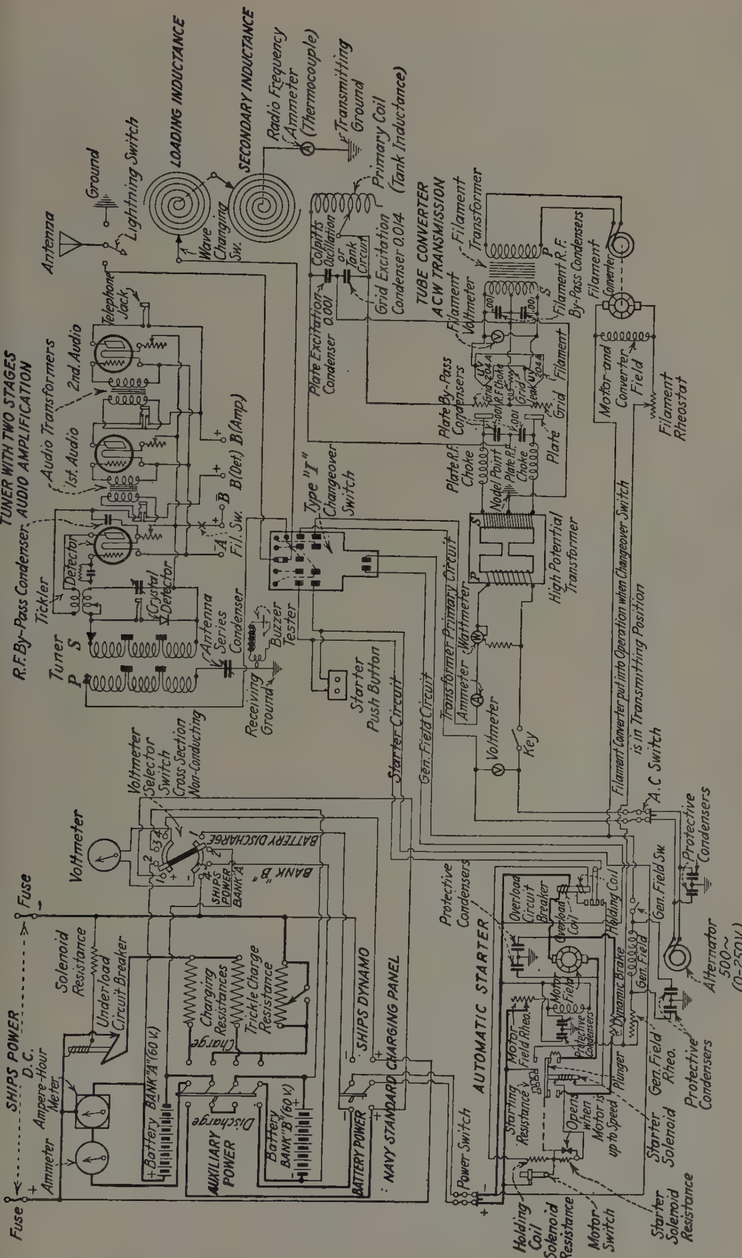


FIG. 161.—Commercial diagram of the P-8 transmitter with tube attachment for the production of full wave A. C. W. transmission.

9. Press the key.

10. Turn the *aerial inductance* handle until a maximum reading is obtained on the aerial ammeter. This will denote resonance between the closed and open circuits. The same procedure is to be followed for other wave lengths.

11. Regulate the power for maximum antenna current by adjusting the generator-field rheostat slider.

For low-power transmission increase the generator-field resistance until the antenna current falls to approximately 2 amp. If this reading cannot be obtained, open the *low-power* resistance on the panel. It is advisable to use the *minimum* of power when operating in the vicinity of coast stations, and also when higher powers are necessary, *not* to exceed 1½ kw. as indicated by the wattmeter.

Troubles and Their Remedies.—In the majority of cases this circuit is extremely stable and very few troubles arise.

Some of the probable causes of the transmitter failing to oscillate, however, is, in most cases, due to poor high-frequency connections in the tank circuit, usually found at the clip of the tank induction, or open-circuit aerial or ground connections.

The tendency for the radiation to be low may be due to the coupling being too tight, on account of the tank-circuit frequency shifting when approaching the antenna resonance period. It may, therefore, be necessary to loosen the coupling slightly, if a defect of this kind is noted. In cases where the antenna is small or the resistance is very low it will be found that the maximum output may not cause an overloading of the tubes to their full rating; and in this case no change should be made to increase the power, with the possible exception of a slight variation in the coupling. This coupling change is obtained by varying the number of turns in the secondary inductance to a very fine degree and *not* by varying the distance between the two inductances.

Fading or Swinging Signals.—Such difficulties may be encountered in the case of a heavy sea causing a variation of the antenna capacity by the rolling of the vessel, for which there is obviously no alternative. Should it be reported, however, that the swinging is of excessive nature, this will be due to the causes mentioned in the previous paragraph: *i.e.*, coupling too tight.

Burned-out Radio Frequency Plate Choke Coil.—This difficulty may be remedied by the insertion of one of the grid chokes in place of the burned out plate choke. Care should be taken to close the grid circuit from which the choke has been taken. If all of the chokes are burned out an equivalent may be used in the form of an 800-turn honeycomb or duo-lateral coil.

Burned-out Grid Leak.—The usual resistance of grid leaks used in this type of transmitter is in the vicinity of 5,000 ohms and should the original burn out it may be replaced by an approximately equal resistance. Where this is impossible, a rubber hose about 10 in. long, filled with salt water and plugged at both ends with a cork, with wires extending from each of these ends into the water, may be used with satisfaction.

Failure of the Filament Converter to Start.—This may be due to the filament lighting resistance connected in series with the converter having a loose connection or burned-out resistance coil. However, this is quite rare and the trouble is usually found in the resistance being completely *on*, thereby allowing a lower amount of current to flow into the motor-winding when starting. This can immediately be remedied by giving the armature a slight turn with the hand.

Burned-out Filament Transformer, Filament Converter, or Filament Rheostat.—Disconnect the entire converter system, including the transformer and filament resistance, and connect the filaments of the tubes directly across a storage battery having an equivalent voltage to the transformer, *i.e.*, 10 volts, *not more.*

Burned-out Radio Frequency Ammeter.—Shunt the meter out of the circuit and for further reference refer to the wattmeter and the tuning record card on the panel.

Important Suggestions.—Should an occasion ever arise where the operator finds that one of the tubes has become inoperative and no spares are available, the transmitter may still be used quite efficiently as a half-wave oscillator.

If both tubes become inoperative and no spares are available, as the only remaining alternative, the operator may connect his transmitter in *plain-aerial* style. This is accomplished by removing all of the connections from the three secondary terminals of the plate transformer and connecting the antenna to one outside secondary terminal of this transformer, and the ground to the

other side of the transformer. The safety gap shunted across the secondary terminals will then function as an oscillatory spark discharger.

R.C.A. 200-WATT RADIO TELEGRAPH TRANSMITTER FOR CW AND ICW TRANSMISSION TYPE ET-3627A. WAVE-LENGTH RANGE 600 TO 960 M.

Foreword.—This transmitter is one of the most efficient low-power tube systems in commercial use today and is an extremely compact arrangement with surprising simplicity in operation.

The circuit embodies the well-known master oscillator system, in which vigorous oscillations are produced by the oscillator and then amplified through one or more tubes in parallel.

The 200-watt transmitter uses one UV211 tube as an oscillator and two UV211 tubes connected in parallel as power amplifiers.

Practical Operation.—The filaments are lighted in parallel by a step-down transformer having an input frequency of 40~ supplied by the motor generator. The voltage for the filament is regulated by means of the filament rheostat up to a point indicating 10 volts at the filament voltmeter.

Adjust the plate voltage by means of the plate rheostat up to 750 volts. This may be increased gradually after the transmitter is properly functioning at the minimum voltage.

Place the signal switch on to the *continuous wave* point and close the key.

Adjust the master oscillator variometer for the desired wave length.

Resonate the antenna circuit by means of the antenna variometer until a maximum defection is obtained at the aerial ammeter.

If the ammeter fails to indicate, it may be necessary to vary the inductance at the antenna inductance switch. Move the variometer slowly in the event that the antenna resistance is low, which will necessitate critical tuning adjustment.

The plate voltage may now be raised to 1,000 volts, but care must be taken that the tube plates do not exceed a dull red.

The maximum antenna current should be obtained with a plate current not exceeding 0.6 amp. at the plate ammeter.

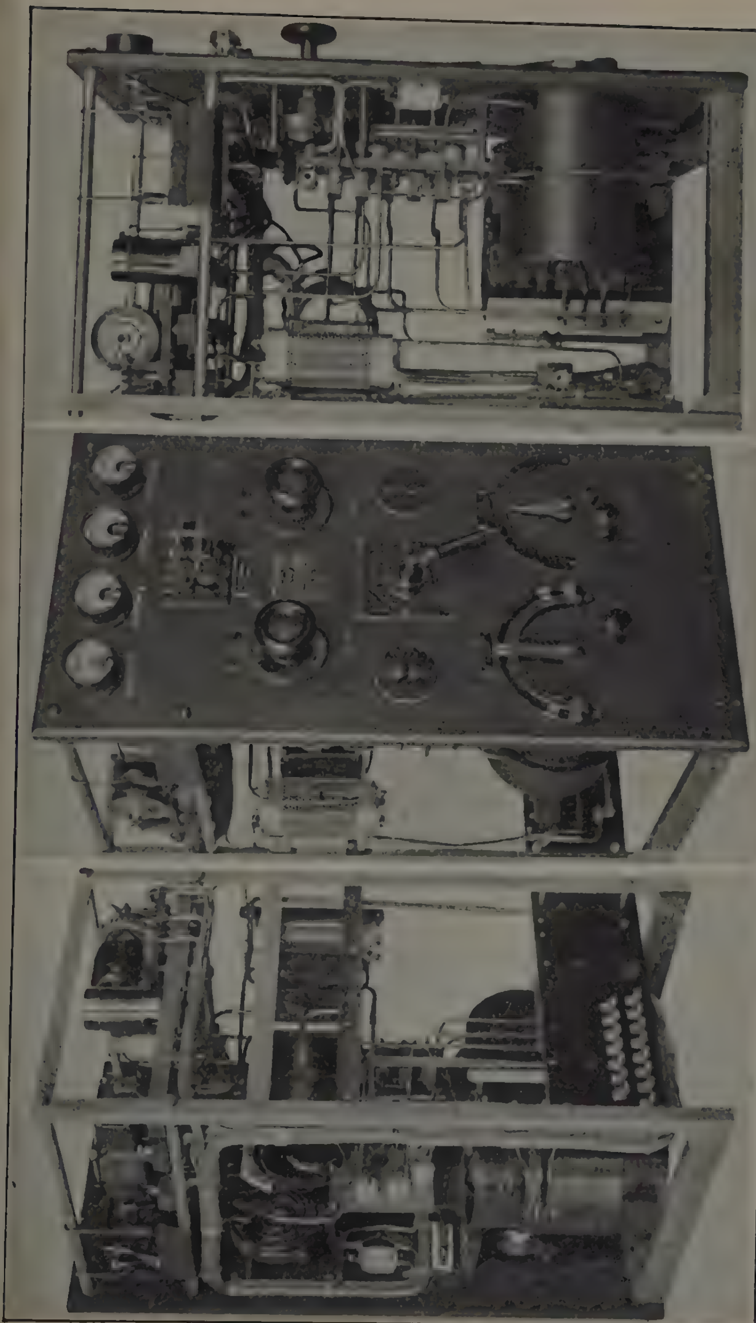


FIG. 162 *a*, *b*, *c*.—Rear, front and side views of R.C.A. 200 watt transmitter ET3627A.

Where high-capacity antenna systems are installed practically all of the plate inductance should be used for continuous wave transmission.

However, in the case of antennas having a capacity of 0.0006 mf. or less only a part of the plate inductance need be used. In the case of interrupted continuous wave transmission it will never be necessary to use all of the inductance so as to permit the interrupted continuous wave to possess very sharp characteristics. This may cause an average drop in the antenna current readings as compared with the continuous wave adjustments but this is compensated for by the gain in sharpness of the emitted wave.

The average antenna current for the interrupted continuous wave adjustment should be between 4 and 6 amp. and for continuous wave between 6 and 10 amp. It must be remembered that maximum radiation is entirely dependent upon antenna capacity and the operator must therefore carefully select the proper tap of the plate inductance for either case.

The proper antenna characteristics for this transmitter are as follows:

Antenna resistance 2 to 10 ohms.

Antenna capacity 0.0004 to 0.001 mf.

Fundamental wave length 175 to 350 m.

The lead X in Fig. 163 is the one referred to in making plate inductance changes for continuous wave or interrupted continuous wave transmission.

It is advisable here to decrease the plate potential to 750 volts while making these adjustments.

If this should necessitate handling the bare clips, *open* the plate-potential circuit.

An interrupted continuous wave is obtained with this transmitter by the use of a chopper system connected in the amplifier and grid leads, properly shunted by a resistance and a condenser and is placed into operation by starting the chopper motor. The chopper wheel and brushes must be kept in good condition to obtain a clear note. This is accomplished by observing the brush pressure upon the chopper commutator, so that it will rest in an even position, and maintaining the segments of the commutator with a polished surface by cleaning with a very fine sandpaper or cloth.

List of Parts and Their Function
(See Fig. 163)

A1. Antenna ammeter—for indicating antenna resonance with plate coil.
C1. Master oscillator plate condenser—for the plate excitation of the oscillator tube.
C2. Filter condenser—for filtering the high-voltage *ripples* from the generator commutator.
C3. Filament by-pass condenser—for providing a path of low reactance for high-frequency oscillations which would otherwise be impeded, due to the inductive reactance at high frequencies of the filament lighting transformer secondary.
C4. Key condenser—for key-arc absorption.

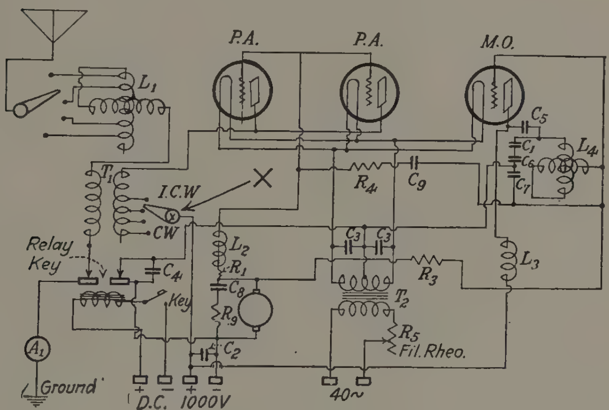


Fig. 163.—Circuit diagram tube transmitter ET-3627A—RCA.

C5. Master oscillator blocking condenser—for preventing a grid and plate short-circuit through the variometer L4. But allowing high-frequency oscillations to by-pass.
C6. Master oscillator plate condenser—same as C1.
C7. Master oscillator grid condenser—for the grid excitation of the oscillator tube.
C8. Chopper condenser—for smoothing out chopper irregularities.
C9. Power amplifier grid condenser—for by-passing radio frequencies flowing in amplifier grids from the master oscillator.
F1. Plate fuse—for protection against filament to plate short-circuits, due to defective tubes or wiring, etc. (not shown).
K1. Key—for *making* or *breaking* the radio frequency oscillations into code groups.
R1. Power amplifier grid resistance—for grid stabilization.

R2. Key resistance—for key-arc minimization in conjunction with C4.
R3. Master oscillator grid resistance—same as R1.
R4. Power amplifier feed resistance—for controlling the grid e.m.f. to the grid of the power-amplifier tubes (feed resistance).
R5. Filament rheostat—for adjusting the filament voltage to 10 volts.
R6. Master oscillator resistance—for the dissipation of stray parasitics which may occur in the oscillator grid leads (not shown).
R7. Plate-field resistance—for the proper control of the plate potential.
R8. Power amplifier parasitic resistance—same as R6 (not shown).
R9. Chopper resistance—for smoothing out chopper irregularities in conjunction with C8.
T1. Plate inductance—for the proper adjustment of oscillations for continuous wave or interrupted continuous wave transmission and also for the purpose of transferring the energy from the closed to the open radiating circuit.
T2. Filament transformer—for *stepping* the voltage down to the proper value of the tubes and provided with a suitable current winding.
V1. Filament voltmeter 0 to 15 volts—for ascertaining the proper filament voltage (not shown).
V2. Plate voltmeter 0 to 1500 volts direct-current—for ascertaining the proper plate potential supplied to the tubes (not shown).
L1. Antenna inductance—for resonating with the closed circuit and obtaining wave-length variations.
L2. Radio frequency choke—for maintaining the flow of oscillations to the power amplifier grids from the feed resistance R4 steady.
L3. Radio frequency choke—for maintaining the high-frequency flow in the master oscillator plate circuit through the oscillatory circuit C5, C1, C6, and L4 constant and to keep radio frequencies from the D.C. generator circuit.
L4. Master oscillator wave changer (variometer).

Break-in Relay.—This device consists of two pairs of contacts, one pair being connected with the low-potential end of the antenna system and the other pair connected in the key circuit of the transmitter. Whenever the antenna contacts are open, the radio receiver is connected through the antenna inductance, and when they are closed automatically they short-circuit the receiver, thereby protecting against high-voltage surges. During the period that the key circuit of the transmitter is closed, the receiver contacts must close a fraction

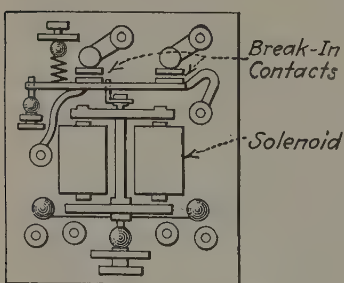


Fig. 164.—Leach break-in relay.

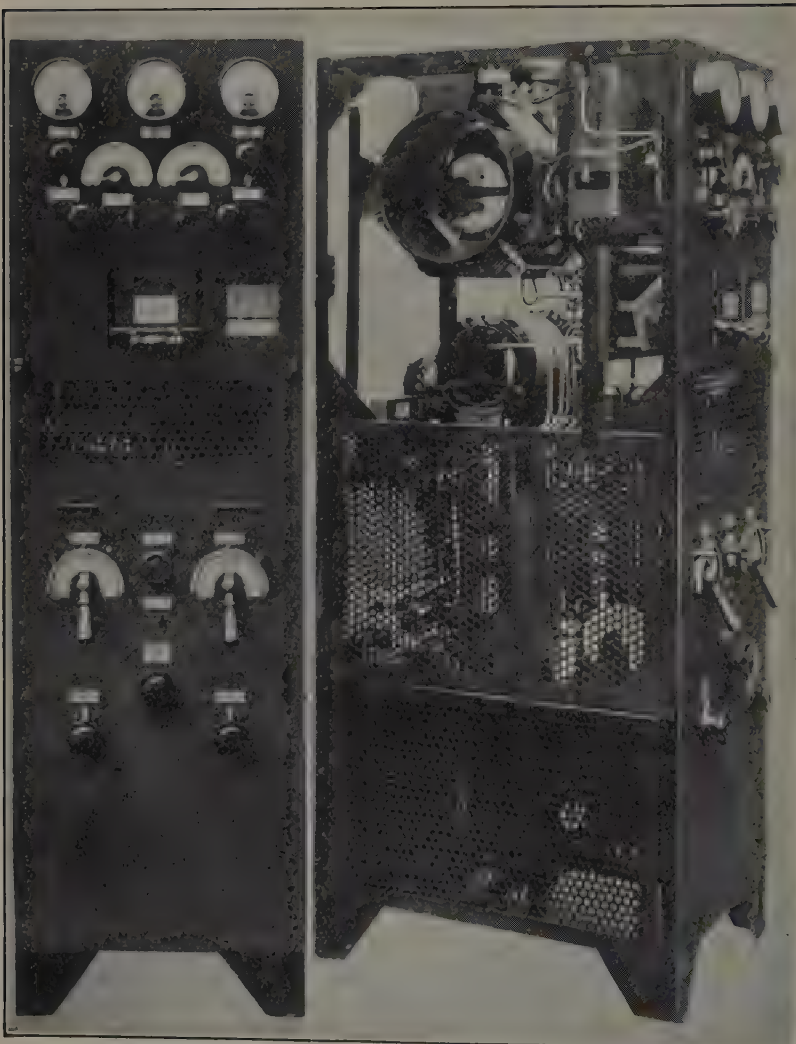
of a second before to insure against possible *burn-out* of the receiver. This is accomplished by carefully adjusting the contact spring on each pair so that the spacings on the antenna contacts are about ⅛ in. less than the key contacts. When the proper adjustment is obtained, a slight spark will occur at the key contacts and a slightly larger one at the antenna contacts.

Troubles and Remedies.—Refer to the 500-watt tube transmitter type ET3626A next described.

R.C.A. 500-WATT TUBE TRANSMITTER—MODEL ET3626A

Foreword.—This transmitter (Fig. 165*a* and *b*) is one of the higher-power types now used in the commercial field for the production of continuous waves and interrupted continuous waves. It provides for transmission on two bands of wavelength, *i.e.*, 600 to 1,250 m. and 1,250 to 2,500 m. The lower wave band permits an output of from ½ to ¾ kw., on both continuous wave and interrupted continuous wave. The higher wave band permits an output of ½ kw. continuous wave. The interrupted waves are obtained by a chopper system with a tone characteristic of 500 cycles. Two UV211 tubes are used as master oscillators, connected in parallel, with six UV211 tubes as power amplifiers. Oscillations are obtained by the Hartley, *split-inductance* method. The key circuit, consisting of a relay, automatically controls the grid circuit in such a manner as to stop oscillations by applying a negative grid potential of 250 volts to both the master oscillator and the amplifier tubes when the key is open to protect against *overloading*. The additional contacts on the key permit break-in operation as mentioned in the 200-watt transmitter. The plate supply is delivered by a 1,000-volt two-pole direct-current generator and the filament supply, of 77 volts, 60 cycles, single phase, is obtained from the slip rings on the motor of the motor generator. The motor is a four-pole compound-wound machine designed for 110-volt use.

Practical Operation.—Examine the following scale for determination of the proper number of taps to be used on the short-wave or long-wave coil starting at the bottom of the coil and counting up.



(a) (b)

FIG. 165a. and b.—RCA 500-watt tube transmitter model 3626A.

Tap marked	Short-wave coil, number of turns	Long-wave coil, number of turns
Grid	27	51
Gnd	21	34
Neutralizing condenser	18	27
W. L.	12	15
Plate	0	0

The automatic starter bar should rise in about 2 sec. after the button has been pressed. If it should fail to do this, adjust the acceleration by the set screw directly underneath the magnet coil and then, after the proper *timing* has been obtained, tighten the locknut.

Start the motor generator and throw the transfer switch to the point marked *short-wave* and adjust the master oscillator variometer to about 600 m. Adjust the filament voltage to 10 volts and the plate voltage to about 800. Press the key and note the plate ammeter reading. This should be about 0.9 amp. Adjust the short-wave antenna tuner until a maximum indication is obtained at the antenna ammeter. At this point the plates of the tubes should be dull red. If they are, the plate potential may be increased to 1,000 volts. The plate current indicated by the plate ammeter will now indicate between 1.2 and 1.4 amp. If this reading cannot be obtained, decrease the number of turns in the primary circuit of the coupling transformer. It is best to begin with a maximum number of turns and gradually decrease until the required number of amperes is obtained on the plate ammeter. *Never* increase the plate current beyond the point where the antenna ammeter fails to increase further.

The transmitter is now adjusted for 600-m. transmission, and the entire range may be adjusted in exactly the same manner.

When the chopper is used, the above procedure is not affected but a slight decrease in the antenna current reading will result.

The antenna currents for the various bands should be in the vicinity of 10 amp. This of course varies slightly with the antenna resistance and capacity.

LIST OF PARTS AND THEIR FUNCTION

(Refer to the Diagram: Fig. 166)

1. Choke coil—for preventing the radio frequencies from returning through the generator lead.

2. Blocking condenser—for by-passing the plate radio frequencies and also to separate the direct current from the oscillating circuit.

3. Master oscillator-tuning inductance—for adjusting to the various frequencies (wave lengths).

4. Master oscillator condensers—for varying the "frequency period" of coil 3.

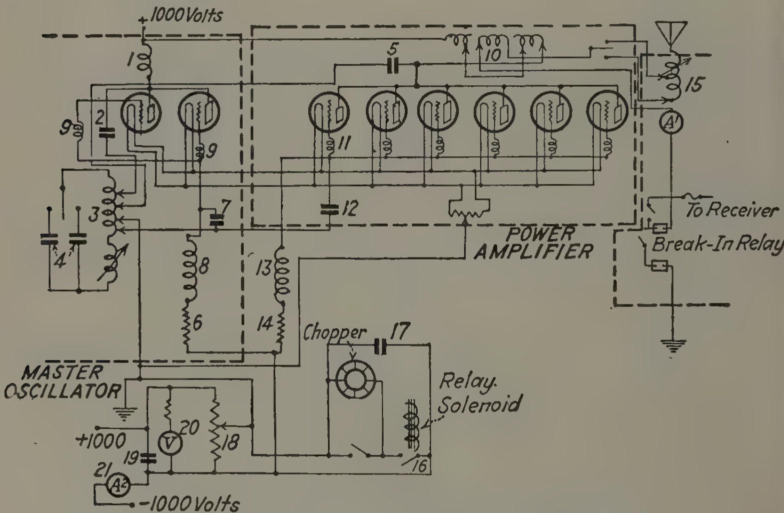


FIG. 166.—Circuit model 3626A tube transmitter RCA.

5. Neutralizing condenser—for the prevention of feed-back from the plate to the grid of the power-amplifier tubes, due to their internal capacity.

6. Grid-leak resistance—for maintaining the proper bias on the grids of the tubes while oscillating.

7. Grid blocking condenser—for by-passing the radio frequencies in the grids of both the master oscillator and power amplifier circuits.

8. Radio frequency choke coil—for preventing the grid frequencies from passing through the keying circuit.

9. Radio frequency choke coil—for the prevention of self-oscillation at extreme frequencies.

10. Plate-coupling transformer—for the excitation of the antenna system.

11. Radio frequency choke coil—same function as 9.

12. Grid-blocking condenser—same function as 7.

13. Radio frequency choke coil—same function as 8.

14. Grid-leak resistance—same function as 6.

15. Antenna variometer—for tuning the antenna system to resonance with the master oscillator—amplifier circuit.

16. Key relay—explained in Foreword.

17. Key or chopper condenser—for key-arc absorption.

18. Potential divider—for supplying the proper grid bias to the tubes.

19. Low-frequency filter condenser—for smoothing out the commutator *ripples* from the 1,000 volt generator.

20. Direct-current voltmeter—for indicating the proper plate voltage to be used.

21. Direct-current ammeter—for indicating the proper plate currents to be used.

PROBABLE TROUBLES AND THEIR CAUSES

1. Motor-generator Fails to Start.—Look for an open switch or *blown* fuses. Line voltage too low. Ships power *off*.

2. Starter Circuit Closes but Motor Fails to Start.—Look for burned-out starter resistance. Bearings frozen due to the lack of oil.

3. Filaments Fail to Light.—Look for *burned-out* filament fuses, dirty collector rings, loose connections and defective fuses.

4. No Antenna Current.—Look for loose, dirty connections. Antenna circuit not in resonance.

5. Tubes Overloading.—Look for a defect in the bias resistance 18. Defective amplifier tube is indicated by a blue haze. Circuit not oscillating. Defective oscillator tubes. Defective coupling. Improper number of plate turns.

6. Burned-out Tubes.—If no spares are available, operate at reduced power by using but three or four amplifier tubes. One oscillator tube may be used under the latter conditions.

7. Burned-out Radio Frequency Plate Choke.—Take out one of the grid chokes and replace. Close the grid circuit with a wire jumper.

8. Blocking Condenser Short-circuiting.—Use one of the other wave condensers.

9. Burned-out Plate Ammeter.—Replace with a 150-watt lamp which should not exceed a normal brilliancy.

10. Voltmeter Inoperative.—Adjusting the generator field rheostat at a normal position is the only alternative.

11. Burned-out Filament Transformer.—Use storage cells to the amount of 10 volts and connect with heavy leads to handle the filament current.

12. Burned-out Grid Leak.—Use a 60-watt lamp in the power amplifier lead and if in the case of the master oscillator use a resistance having a value of approximately 5,000 ohms.

Important Don'ts:

Do not adjust bare circuits while the generator is running.

Do not operate the filaments at a point exceeding 10 volts on the filament voltmeter.

Do not increase the plate potential above 1,000 volts on the direct-current voltmeter.

Do not clean commutators while the generator is in motion.

Do not oil the chopper commutator.

Do not oil high-frequency connections with the object of preventing corrosion.

Important Suggestions.—Keep all contacts on inductances and switches thoroughly cleaned. Keep the chopper commutator polished by using *very* fine sand paper (*preferably* of No. 00 gage).

Keep the relay contacts in the same condition.

Keep dust from all high-frequency devices to prevent voltage break-down due to creepage.

Keep all moving parts well oiled.

Questions

1. Explain how to place the P-8 tube converter into operation.
2. Where would the trouble be if the transmitter failed to oscillate?
3. What would cause poor radiation?
4. What might cause fading or swinging signals?
5. What is the remedy for a burned-out choke?
6. What is the remedy for a burned-out grid leak?
7. Where would the trouble be if the filament converter failed to start?
8. What would be the remedy for a burned-out filament transformer?
9. If one tube becomes inoperative and no spares are available, can the transmitter still function?
10. Draw diagram of the tube-converter unit.

CHAPTER XXII

PRACTICAL OPERATION VACUUM-TUBE RECEIVERS

Vacuum-tube Receivers.—The last part of Chap. XVI describes in detail the tuning operations for a crystal detector set. In general, the operation of a vacuum-tube receiver is similar. The additional equipment on a vacuum-tube receiver consists of tubes, batteries, tickler coil, amplifiers, and, in some cases, extra condensers and inductances. It is sometimes desirable to locate the batteries at some distance from the receiver.

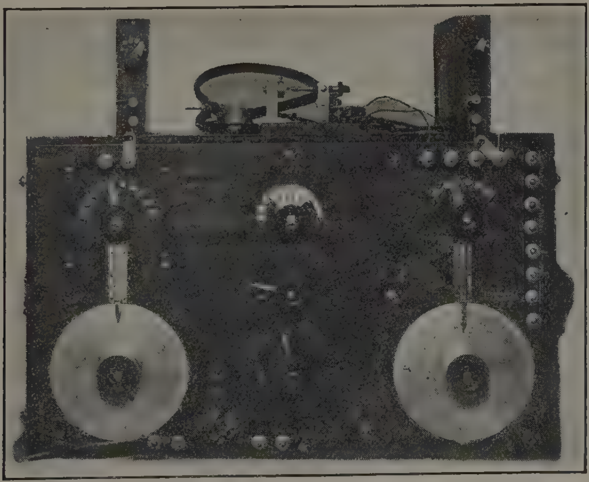


FIG. 167.—Navy standard type S.E. 143 tuner.

The various instruments in a set enclosed in a cabinet should be carefully placed with each separate circuit as compact as possible. Amplifying transformers are placed at right angles to each other to avoid howling in the tubes. A heavy copper strip called "bus wire" is used to interconnect the apparatus. A later method uses a rubber-covered wire for this purpose.

A modern type of commercial receiver is shown in Fig. 167. On the panel is seen the following controls: primary inductance switch, secondary inductance switch, primary condenser (marked primary wave lengths), secondary condenser (marked secondary wave lengths), stopping condenser, tickler coupling, inductive coupling, detector switch for shifting from a crystal to a vacuum-tube detector. There is also a switch marked *tuned-untuned* which permits the use of a stand-by or a tuned circuit. A test buzzer is also provided for testing the crystal detector. In the upper left-hand corner are located two binding posts which ordinarily are short-circuited, but to which may be connected a loading coil, as shown, if it is desired to raise the tuning limit of the set. A similar set of posts is located on the upper right-hand corner for the secondary load coil. Next to the secondary load coil is a pair of posts to which an outside crystal detector may be connected. Terminals for the aerial, ground, and headphones are also provided. The vacuum-tube detector is connected to the two lower terminals on the right of the panel.

Practical Operation.—To operate the set as a crystal receiver, proceed as was explained in Chap. XVI. To operate the set as a vacuum-tube receiver, it is necessary to throw the detector switch to the proper position and light the vacuum tubes, which are in a separate cabinet located on one side of the receiver. The first tuning operation is to set the inductive coupling at maximum and vary the tickler coupling in the vicinity of maximum until signals are heard. It is, of course, necessary that the ordinary inductance and capacity adjustments be made in the primary and secondary circuits in the same ways as when the crystal detector was used. It is impossible to set down in writing the exact directions for tuning-in signals at any station; this can only be accomplished by practice. If difficulty is experienced in receiving signals, check over all connections carefully, especially those leading from the vacuum-tube batteries. When operating a regenerative receiver, such as the one in Fig. 167, it is necessary that very close adjustments to the desired wave length be made. To provide for this, special knobs are located in both lower corners marked *fine adjustment* (in some cases they are called "verniers"), which provide for a very finely graduated capacity through a system of gears or cogwheels.

Beat Reception.—When receiving undamped waves with this receiver it is necessary that the vacuum-tube oscillating circuit be set in oscillation; otherwise the *beats* will not be produced and the signals not heard in the headphones. To make the circuit oscillate, a careful adjustment of the tickler coupling, secondary

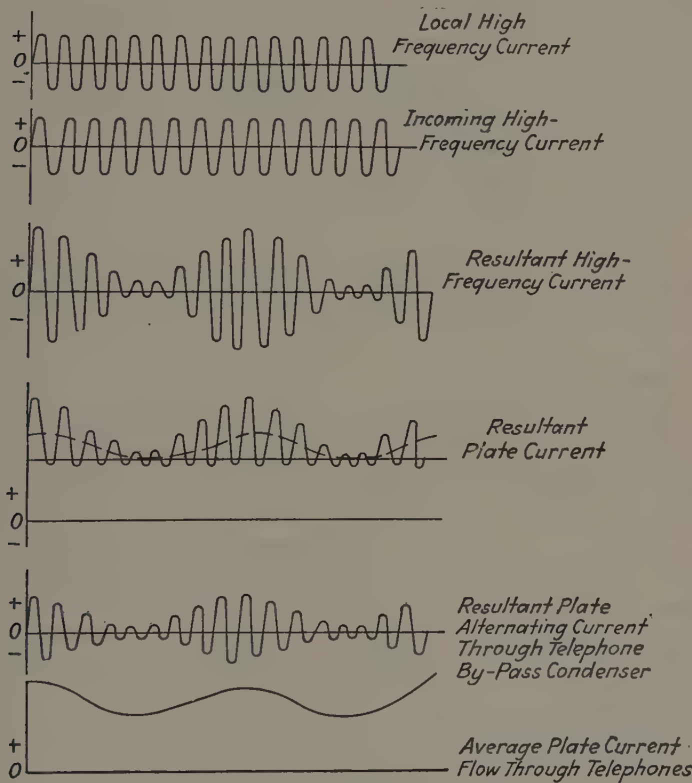


Fig. 168.

inductance, and capacity is necessary. A characteristic "cluck" will be heard in the headphones as the circuit is thrown into oscillation.

Continuous-wave Reception.—Continuous waves such as are radiated by the arc or vacuum-tube oscillator cannot be heard with the crystal detector, due to the fact that they oscillate at radio frequencies which, due to their unvarying amplitude and

very high frequency, do not act upon the headphone diaphragm. It is necessary, therefore, to produce an audio frequency current in the headphone circuit. This may be done in several ways; by means of a chopper or Poulsen *tikker* as it is sometimes called, which was explained in connection with the arc transmitter; by means of a rotating condenser at high speed, a method little used and not to be discussed; and by means of the vacuum tube in either a heterodyne or regenerative receiving circuit. These last two methods are the only ones used in modern installations.

The action in a beat receiver is shown in Fig. 168. Here it is seen that the incoming oscillations meet those generated locally and the resultant is the beat current of a varying amplitude. This beat current finally produces low-frequency pulses in the plate circuit and these affect the headphone diaphragm. In the upper two curves, counting from the left, the first, fifth and ninth cycles reach their maximum values at the same instant, resulting in a beat current shown by the third curve. The rectifying properties of the vacuum tube produce a plate current as shown by the fourth curve and the audible changes in the plate current which reach the telephone receivers are shown by the bottom curve.

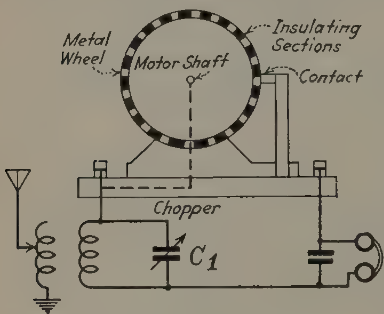


Fig. 169.—Poulsen tikker.

Another means of producing audio frequency pulses in the headphone circuit is by means of the Poulsen *tikker* or *chopper:* The tikker is shown in Fig. 169 and is connected as shown in the diagram. The continuous oscillations coming into the aerial circuit are induced into the secondary circuit of which the *tikker* is a part. The wheel of the tikker is of metal and is conducting, except for the evenly spaced insulated sections around the edge. When the brush touches an insulated section, the oscillations, which have been induced into the circuit and have charged the condenser C_1, discharge into the telephone condenser at regular intervals, according to the speed of the wheel—generally from

300 to 1,000 times per second. The telephone condenser, in turn, discharges through the headphones and produces a click. These clicks, coming in very rapid succession, produce a continuous sound. In this way, continuous or undamped waves are made audible in the headphones.

Slipping Contact Detector.—Another form of mechanical interrupter which breaks up the continuity of continuous oscillations is the slipping contact detector. This consists of a smooth brass wheel which has a stationary, fine steel or gold wire making contact with it. The wheel and the wire make an imperfect contact due to the rotation of the wheel, and the secondary condenser is charged in the same way as with the tikker. The headphone condenser is likewise charged from the discharge of the secondary condenser and a continuous sound is produced in the headphones. In mechanical appearance the tikker and the slipping contact detectors appear the same. Electrically, their action is similar. They are, however, used to a very limited extent at the present time, having been replaced by the vacuum tube.

Undamped or continuous waves may then be made audible in the headphones by means of the heterodyne, regenerative receiver, the tikker, the slipping contact detector, and the Goldschmidt tone wheel which is similar to the tikker.

Sensitivity of Vacuum Tube.—The sensitivity of the vacuum tube depends upon the correct filament brilliancy, the correct plate voltage, and the correct kind of a tube for the function to be performed. As was explained before, some tubes make better detectors than amplifiers and vice versa. The filament should not be burned too brilliantly but may be adjusted while signals are being received and the adjustment of the A battery rheostat left at the point of maximum signal strength. When shutting off the vacuum tube, do so by increasing the resistance of the filament rheostat until the filament is so dim that is can scarcely be seen. The switch which controls the filament current may now be opened. If the filament battery now recuperates while it is idle it will not burn out the filament should the switch be closed, for the rheostat is at a maximum resistance and the filament burns dimly. When beginning operations again it is, of course, necessary to increase the filament to the proper brilliancy.

The plate battery should also be carefully watched as this battery frequently goes dead when least expected.

For efficient operation, a proper plate voltage is absolutely necessary.

Wavemeters.—The wavemeter is the most important measuring instrument used in radio. It consists of an inductance and a capacity, either or both of which may be variable. It is, however, the practice to make the inductance of fixed value and the capacity variable. A wavemeter circuit with a buzzer attached is shown in Fig. 170.

The buzzer circuit may be disregarded, for the present, and attention centered on the inductance and capacity.

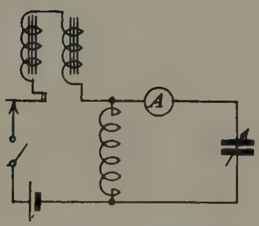


Fig. 170.—Wavemeter.

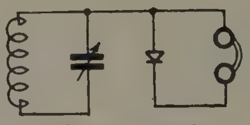


Fig. 171.—Methods of connecting crystal detector to wavemeter.

Operating Principle of Wavemeter.—Every oscillatory circuit has a period of oscillation or wave length; this depends upon the value of the inductance and the capacity. In a wavemeter the wave length is changed by varying the condenser (capacity). By such variation the wavemeter may be put in resonance with any other oscillating circuit within its range. Resonance on the wavemeter may be indicated by any of the following methods:

1. Glow lamp.
2. Current-indicating instrument.
3. Detector and headphones.

The glow lamp indicates resonance by its maximum brilliancy and is a low-voltage lamp connected at the point *A* in the diagram. It is very seldom employed in modern wavemeters.

The current-indicating device which is usually a milliammeter designed to measure very small currents may be either of the hot-wire or thermocouple type. Its scale is usually graduated so as to read values proportional to the square of the current (I^2).

The detector and headphones, as indicated in Fig. 171, give auditory indication of resonance. The loudest signal is heard in the headphones at the point of resonance. With this method it is, of course, impossible to measure the proportional value of the current at resonance, due to the inaccuracy of the human ear.

When the current-indicating meter is used, resonance is indicated by the maximum reading of the meter. The value of the reading is, of course, an indication of the current flowing in

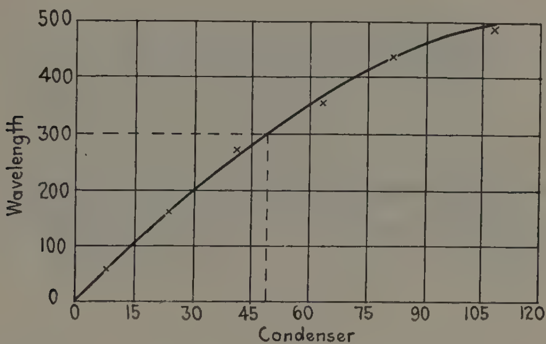


Fig. 172.—Wavemeter chart.

the wavemeter circuit. This, in turn, depends upon the proximity of the wavemeter to the oscillating circuit under measurement, and would vary inversely with the distance between the wavemeter and the circuit.

Calibration.—There are two types of wavemeters, direct and indirect reading. The direct-reading type gives the actual wave length or wave frequency directly on a dial affixed to the wavemeter. The wave length or wave frequency on the indirect-reading type is deducted by taking a dial reading from the wavemeter and referring to a curve such as shown in Fig. 172. All but the direct-reading types of wavemeters are supplied with such a calibration curve. A study of the curve will show that the wave length may be read by reading the relationship of the

curve to the condenser readings and the wave lengths as indicated along the base and side of the cross-section paper.

As an example, suppose the condenser reads 50 deg. The point on the curve in Fig. 172, opposite the condenser reading, is also opposite 300 on the wave-length scale on the curve sheet. Three hundred meters is, therefore, the wave length.

Indirect-reading Wavemeter.—A complete indirect reading wavemeter is shown in Fig. 173. The capacity is a variable condenser inside of the case and the inductances are supplied in three sizes for three ranges of wave length. Inductance *A* will measure from 150 to 800 m.; inductance *B*, from 800 to 2,600 m.; and inductance *C*, from 2,600 to 10,000 m.

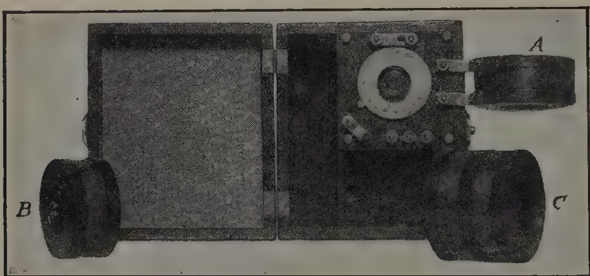


Fig. 173.—General Radio Company wavemeter.

On the calibration curve sheet, which is in the cover, there are three curves, one for each inductance. The inductance to be used depends upon the wave length to be measured.

As an example of actual operation, suppose that the condenser dial reads 50 deg., using inductance *A* and that by referring to the curve we can find that the wave length is 510 m. The abscissa or base of the curve paper reads wave lengths, while the condenser readings are plotted as ordinates or vertically. The wave-length reading opposite the point where the curve crosses the condenser dial reading is the wave length to which the meter is adjusted.

A wavemeter is calibrated from another wavemeter acting as an oscillating circuit at a known wave length. A buzzer, connected as shown in Fig. 170, will excite the wavemeter circuit at any wave length within the range of the meter.

Calibration of a wavemeter would require separate readings for every two or three units on the condenser scale. Actual calibration is done as follows:

1. Set the standard wavemeter into oscillation at its lowest wave length.
2. Couple the wavemeter that is to be calibrated to the oscillating wavemeter, and place a dot on the cross-section paper at the point of intersection of two vertical lines drawn from the condenser reading, and wave-length reading, on the curve paper. These vertical lines may be drawn with a pencil and erased later, leaving only the dot at the point of intersection.
3. Raise the wave-length of the oscillating wave-meter 25 m.
4. Repeat operation Number 2.

The above may be continued until the entire range of the wavemeter under calibration has been covered. A curved line is then drawn through the dots on the cross-section paper.

The condenser capacity may vary from .00025 to .002 mf., depending upon the range of the meter. The graduations on the condenser dial are in evenly divided units and vary with the different types in use.

Wavemeter as an Oscillator.—It is sometimes desirable to calibrate a receiving set or another wavemeter. In such cases the wavemeter circuit is adjusted to a given wave length and excited by a buzzer, as in Fig. 170.

The receiver or wavemeter to be calibrated is then placed in close proximity to the wavemeter and adjusted to resonance. A note of the adjustments is made and the next higher wave length is adjusted for the wavemeter; the receiver is again adjusted and another note taken. This is continued as far as desirable.

In permanent receiver installations, it is very desirable to calibrate the receiver as explained above and it is then possible to tell the wave length of any distant transmitter.

Thus far the wavemeter functions have been as follows:

1. To tune a transmitter.
2. To calibrate another wavemeter.
3. To calibrate a receiver.
4. To measure wave length of a distant transmitting station by indirectly calibrating the receiving set and then noting the adjustments for the incoming wave, the wave length of which is desired.
5. To measure decrement.
6. To measure degree of coupling.

There is another function of the wavemeter, namely, to measure the decrement of damping in a spark transmitter. This will now be explained.

Decremeter (Indirect Reading).—Refer to Chap. XIII, Principles of the Radio Transmitter, under the section "Decremeter," where is explained the relation of the decrement to the practical operation of a radio transmitter. Too high a decrement is prohibited by law because of the interference produced by a wave having such characteristics.

Decrement has been explained as being the loss in each alternation of a damped oscillating radio wave. The law says the decrement per complete oscillation shall not exceed two-tenths, except when sending distress signals or similar messages.

Manipulation of Decremeter.—Any wavemeter can be used to measure the decrement of a spark transmitter, if it is fitted with a current-indicating meter.

In radio terminology, the Greek letter δ (delta) designates *decrement* and λ (lambda) designates *wave length* in meters.

To arrive at the decrement of a given damped oscillating circuit the following formula is used:

$$\delta + \delta_1 = 2\pi \frac{\lambda_2 - \lambda_1}{\lambda_2 + \lambda_1}.$$

Where δ = the decrement of the circuit under measurement.

δ_1 = the decrement of the decremeter (wavemeter).

λ_1 = the wave length of the circuit under measurement, longer than the resonance wave which reduces the wattmeter reading to one-half that of the reading at resonance.

λ_2 = the wave length of the circuit under measurement, shorter than the resonance wave which reduces the wattmeter reading to one-half that of the reading at resonance.

π = 3.1416

When using the above formula, a current-indicating instrument whose readings are proportional to the square of the current (a wattmeter or galvanometer) must be used.

To ascertain the decrement of a circuit two readings are necessary:

First, the wave length above the resonance point where the wattmeter reading is reduced to one-half of the resonance point reading.

Second, the wave length below the resonance point where the wattmeter reading is reduced one-half of the resonance point reading.

The above two readings are then substituted in the formula, and the result is the decrement of the circuit plus the decrement

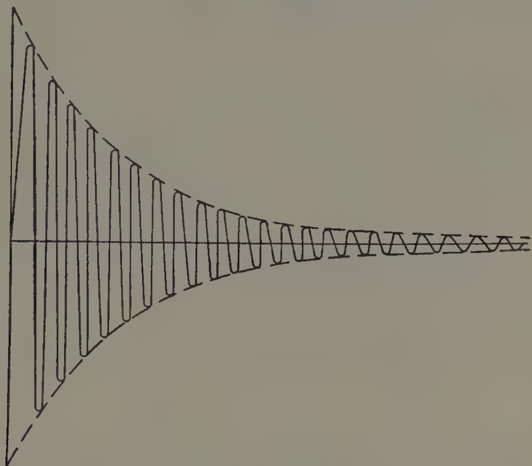


FIG. 174.—A wave train.

of the decremeter. This latter decrement, which is usually given with each decremeter by the manufacturer, is subtracted from the combined value, and the decrement of the circuit under measurement remains.

Figure 174 shows a wave train having a decrement or gradual decrease of current amplitude in each alternation. The value of this loss could be measured by using the above method of measuring decrement.

Figure 175 shows three resonance curves, curve I having an even distribution of energy on both sides of the resonance point, and curve III having an uneven distribution of energy. It is to be noted that the resonance point on both curves is not so sharply defined as the points halfway above and below (marked A^1 and B^1 on the curve I). It is also to be noted that in the formula the reading at resonance is not used but rather the read-

ings halfway above and below the resonance point; this makes for accuracy in the mathematical result. Curve II is very sharp wave, resonance being at point E.

When using the wavemeter to take decrement readings, it should be rather closely coupled to the circuit under measurement. The principle of measuring decrement explained above is known as the "Bjerknes method" and is fairly accurate, provided the damping of the current is not too great.

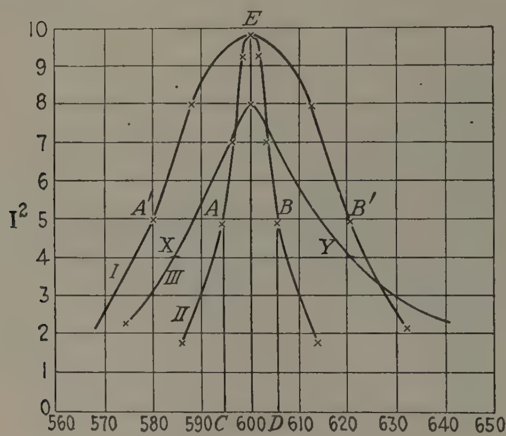


Fig. 175.—Resonance curves.

Kolster Decremeter (Direct Reading).—A type of direct reading decremeter designed for the U. S. Radio Inspection Service and now in general use is shown in Fig. 176*a* and *b*. This instrument gives a direct decrement reading from a dial mounted on the panel face.

To find the decrement of a circuit, the variable condenser, Fig. 176*b*, is first set at resonance as indicated by a maximum reading on the current-indicating meter. This maximum current value is now reduced to one-half the maximum value by decreasing or increasing the capacity of the rotary condenser. The decrement scale, which may be rotated independently, is now set at zero and clamped so that it will rotate with the condenser when it is again rotated.

With the decrement scale at zero and the current meter reading one-half maximum deflection, the condenser is turned completely around past the point where the meter reads maximum, to one-

FIG. 176*a*.—Kolster decremeter.

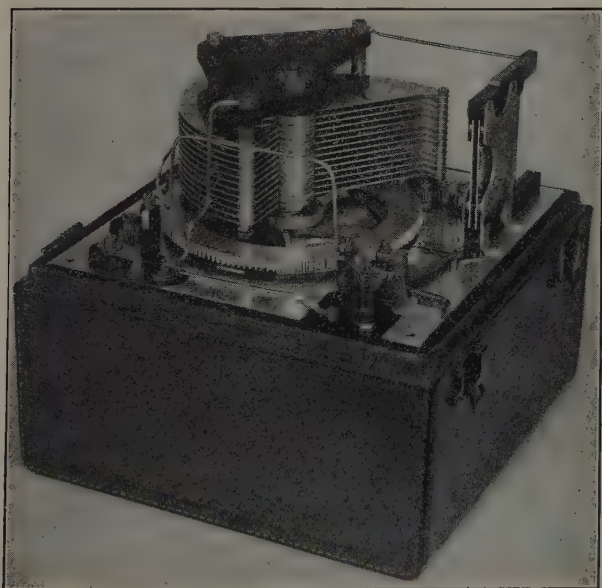


FIG. 176*b*.—Kolster decremeter.

half maximum deflection on the current meter on the other side of the maximum point from the point of starting. The reading on the decrement scale now opposite the index mark 0 is the value of the decrement of the circuit under test plus the decrement of the decremeter itself. The decrement of the decremeter, being given with each instrument, is known and subtracted from the scale reading, leaving as a final result the decrement of the circuit under measurement.

A schematic wiring diagram of the Kolster type D meter is given in Fig. 177. The Kolster decremeter also measures wave

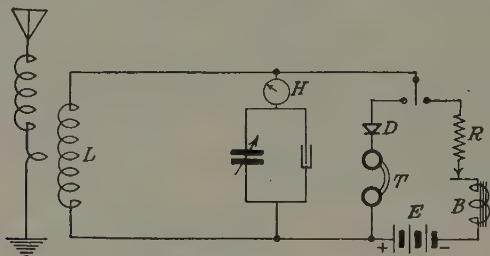


Fig. 177.—Circuit diagram of Kolster decremeter.

length directly in meters on a scale reading. The range of the one in Fig. 176 is 75 to 3,000 m.

Modern practice calls for the use of the Kolster meter exclusively, and the finding of the decrement of a circuit using the Bjerknes formula method is seldom done.

Note.—The U. S. Government Bureau of Standards publishes a booklet (Scientific Paper 235) on the Kolster decremeter which may be obtained by sending 10 cts. to the Superintendent of Documents, Government Printing Office, Washington, D. C.

Questions

1. Explain how to adjust a commercial receiver for continuous-wave reception.
2. Describe a slipping contact detector.
3. Draw a diagram of a wavemeter.
4. How does a wavemeter operate?
5. How are wavemeters calibrated?
6. How can the wavemeter be used as a transmitting system for calibration purposes?
7. Describe the operation of a decremeter.
8. Give the circuit diagram of the Kolster decremeter.

CHAPTER XXIII

COMMERCIAL SPARK TRANSMITTERS AND RECEIVERS

The Simpson Transmitter.—The diagram Fig. 178 shows the high-tension circuits of the Simpson radio telegraph transmitter.

The operation of the Simpson system can be briefly explained as follows: During the interval that the key is depressed the alternating current from the secondary of the high-potential

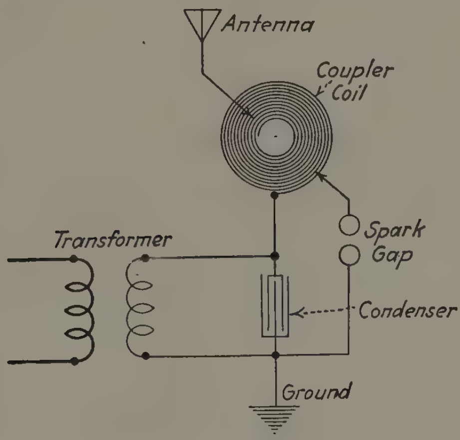


FIG. 178.

transformer charges the condenser in the usual manner. Since the high-tension condenser is connected in series with the antenna system, the latter also becomes charged. The spark gap then acts as a trigger and releases the energy which is stored in the antenna in a static form, thereby converting it into its oscillatory form.

To familiarize the student thoroughly with this type of apparatus, a complete description of the 2-kw. Simpson transmitter as manufactured by the Kilbourne and Clark Manufacturing Company of Seattle, Wash., will be given.

The 2-kw. Simpson transmitter consists of a single panel on which are mounted the various pieces of low-frequency and high-frequency apparatus. The overall dimensions of this outfit are approximately, 63 in. high, by 24 in. wide, by 28 in. deep. Thus it is seen that the set is very compact and suitable for confined spaces. In addition to this unit, a motor-generator and hand sending key are provided. The motor-generator measures 24 in. long by 17 in. high, by 13½ in. wide.

By means of the motor-generator, a direct-current supply is converted into the 500-cycle alternating current required for operation of the transmitter. The power supplied to and from the machine is controlled by switches on the panel. By means of the high-tension transformer the 500-cycle current is then transformed to a high-voltage current for charging the main condenser. As mentioned above, the Simpson system involves the direct coupling of the condenser circuit to the antenna, so that a trigger circuit is provided which discharges the condenser and creates radio frequency oscillations in the antenna of such wave lengths as are determined by the inductance and capacity constants of the circuit. Instantaneous variation of the wave length is accomplished by means of a specially designed switch. The electrical arrangements of the antenna and spark-gap circuits are such as to keep the persistency of the oscillations in the antenna circuit at a maximum. Consequently, the degree of coupling necessary to obtain satisfactory operation is not critical. It is merely necessary to keep the points on the circuit at which the spark gap is connected at nodal potentional, that is, at constant potentional. The wave-changing switch takes care of this requirement automatically.

The transformer is of the resonant type. That is, it produces a resonant circuit with the generator, thereby attaining the highest efficiency.

The panel is of bakelite which is widely used in radio engineering practice. On the front of the panel the following units are mounted:

Direct-current line switch, fused.
Alternating-current line switch, fused.
Two automatic motor-starting units with auxiliary contact for generator field.

One motor-field rheostat-control handle.
One generator-field rheostat-control handle.
Alternating-current voltmeter.
Alternating-current wattmeter.
Aerial ammeter.
Transmitting condenser.
Spark gaps.
Wave-changing switch handle.
Antenna loading coils (mounted above panel)

On the rear of the panel are mounted:

Motor-starting resistance units.
Carbon rod generator field-discharge resistance.
Motor-field rheostat.
Generator-field rheostat.
Transformer.
Wave-changing switch.
Coupling spiral.
Motor-driven blower with fuses and protective device.
Key condenser.
Terminal board.

A wiring diagram of the primary power circuits is shown in Fig. 179. The motor-starting units are of the series-contactor type, the series coils of which are in series with the starting resistance and with the motor armature during the period of acceleration. A shunt coil is provided on the last contactor, which serves to hold the contactor in the *closed* position during operation of the motor. In addition, an auxiliary contact is provided which is connected to the generator field. This serves to open automatically the field when the machine is stopped.

The quenched spark gaps are of the sealed type, and are so arranged that the silver sparking surfaces can be easily inspected. The units are sealed with gaskets of special insulating material which are readily renewable. The sparking surfaces should present a clear, frosty appearance under normal conditions of operation. When a gap unit is first put into operation, the air enclosed and the spark causes a certain amount of oxidation of the silver sparking surfaces. When the gap has sealed, the spark reduces this oxide and the surfaces regain the white color of pure silver.

In order that the operator may test the gap units before attempting to dismantle them, a short-circuiting clip is provided

with the set. By placing the clip across a gap unit and then removing it, an active unit will be found to give a snappy spark of large volume at the instant of removing the short-circuit. On the other hand, an inactive unit will give either a small sluggish spark or no spark at all.

To open the units, remove the six clamping screws, three on each side, and then gently separate the two halves. If the silver surface is found to be black in color, it is an indication that air leaked into the gap while it was discharging. A blue-black spotted appearance, shows that a slight leakage has taken place and that there has been a deposit of silver. If the silver surface

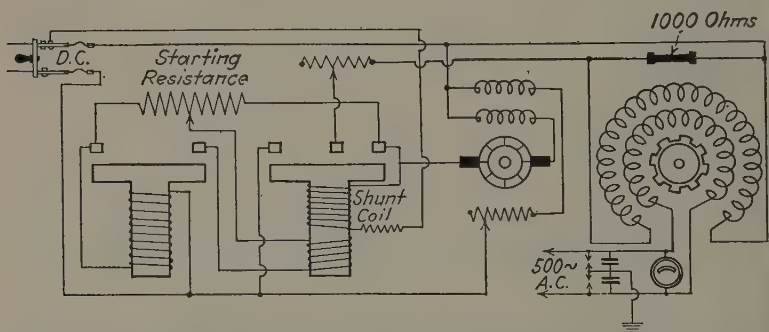


FIG. 179.—Primary power circuits of Simpson 2-kw. radio transmitter. Motor-generator comprises 110-volt direct-current differentially compound-wound motor driving a 500-cycle, 230-volt inductor type alternating-current generator.

has a brown color and is speckled or pitted, the gap has been overloaded. The gap has likewise been overloaded if rough edges on the outer circumference of the sparking surfaces are evident.

The first three conditions can usually be remedied by replacing the gaps and operating them for about 20 min., using an input of about 75 per cent of the rated power. New gaskets, of course, must be employed. If the fourth condition exists, the rough edges can be reduced by scraping them with a knife and then running the gap for 20 min., as mentioned above.

Should the sparking surfaces be in such condition as to require smoothing, use sand paper of No. 000 grade, pasted to a flat block of wood. This latter requirement is necessary in order to keep the sparking surface true. The use of emery in any form should be avoided.

Operators are cautioned not to be too eager to open a gap unit, since every cleaning removes a certain amount of silver and thereby shortens the life of the gap.

The most suitable gap space is usually found to be 0.007 in., or 7 mils. This distance is obtained by using four single gaskets for each gap.

At the rear of the panel a motor-driven blower is mounted, which keeps the gaps cool under conditions of high air temperature such as is experienced in the tropics. The blower motor is connected directly to the direct-current supply line through suitable fuses and a high-frequency protective device. It starts automatically when the direct-current line switch is closed. Outside of an occasional oiling of the bearings, practically no attention need be given this motor.

The transmitting condenser consists of four units having tinfoil conducting surfaces and mica dielectric. The units are impregnated with an insulating compound to prevent surface leakage and are interchangeable.

The wave-changing switch consists of two parts mounted on a dilecto shaft. One part serves to vary the condenser capacity, while the other changes the antenna inductance.

There are four antenna loading coils, each arranged so its inductance can be varied gradually.

The motor-generator unit is similar to those previously described with the exception that the alternating-current generator is of the inductor type. The machine furnished with the particular radio transmitter under discussion consists of a 110-volt, direct-current, differentially compound-wound motor, driving a 500-cycle, 230-volt alternating current, inductor-type generator.

To shield the motor-generator circuits from the high-frequency effects of the transmitter, a protective device is provided. This apparatus consists of two small condensers connected across the alternating-current line with the middle point grounded. A small spark gap is shunted around each condenser. To insure against short-circuiting of the generator in the event of the condensers *breaking down*, fuses are connected between the protective device and the generator. A 1,000-ohm resistance connected across the line provides an additional path for stray effects.

By referring to the diagram in Fig. 180, it will be noted that the antenna used with the Simpson transmitter is divided into two parts, the larger part being used on all wave lengths over 300 m. The smaller part is used for the 300-m. wave length (now obsolete).

The receiving apparatus supplied with this transmitter is enclosed in a finished wooden-case, the over-all dimensions of which

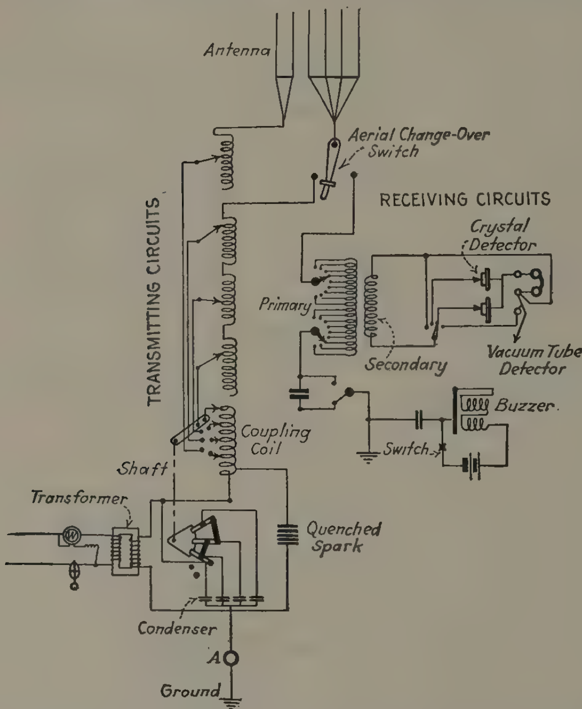


FIG. 180.—Diagram of Simpson radio telegraph transmitter and receiver

are approximately 12 in. wide, by 5½ in. high, by 5 in. deep. The constants of the receiving circuit permit reception up to a wave length of 4,000 m. The switches for varying the primary receiving inductance, as well as the binding posts and other fittings, are mounted on a bakelite dilecto panel which forms the front of the case. From the diagram shown, it will be noted that an untuned secondary circuit is used. It is not necessary that the secondary circuit be in resonance with the primary circuit in

this type of receiver because the secondary circuit is non-oscillatory, due to the high resistance and rectifying action of the crystal detector. Extra terminals are provided to which a vacuum-tube detector may be connected. The coupling between the primary and secondary circuits is variable. A buzzer test circuit is also provided, in order that the detector may be kept adjusted at maximum sensitivity whether or not signals are actually being received.

INDEPENDENT WIRELESS TELEGRAPH COMPANY'S TYPE B-1 SYNCHRONOUS SPARK TRANSMITTER

The type B-1 damped wave radio transmitter designed by the Independent Wireless Telegraph Company is somewhat similar to the Simpson transmitter. The principle involved in the former, however, is somewhat different from that of the Simpson transmitter. In fact, it can be readily said that the Independent transmitter is the simplest commercial radio transmitter made. The spark gap is of the rotary synchronous type and is inserted directly in the aerial circuit as shown in the diagram.

It will be recalled that when a plain or straight gap is connected in series with the aerial and ground, it causes oscillations set up in the aerial circuit to have excessive damping, and consequently a broad wave is radiated. Nevertheless, experiment has shown that under suitable conditions, when the plain gap is replaced with a synchronous rotary gap and proper adjustment is made, the wave radiated will be sharp in the sense that the logarithmic decrement will be 0.2 or less. To study the oscillations that take place in the radiating circuit of the Independent radio transmitter requires the use of an oscillograph, which is a rather delicate laboratory instrument not always available.

Offhand, it may be said that the relation of the stationary electrodes to the periphery of the revolving disc of the gap acts as an effective capacity immediately after each spark discharge. This capacity then acts as a small condenser in series with the aerial and ground, and leaves the antenna system free to oscillate until the next spark discharge occurs. This view, however, is attended with some difficulties, though it is partly strengthened

by the fact that the system operates best when the distance between the stationary and the moving electrodes is great. This is contrary to the adjustment necessary in other types of transmitters employing synchronous rotary gaps, and tends to indicate that the spark must be of extremely short duration: that is,

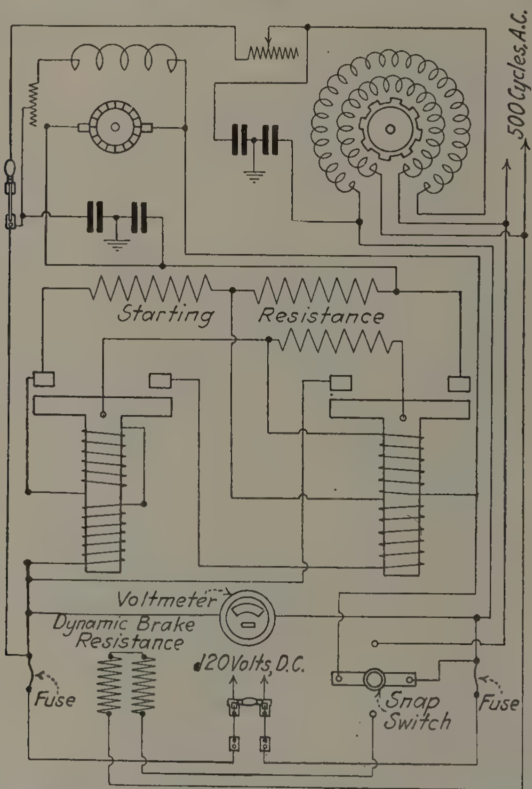


FIG. 181.—Circuit diagram motor and generator, independent spark transmitter.

the quenching must be rapid enough to permit the system to oscillate freely and with as little conversion of the energy into heat and light as possible.

The Independent transmitter is rated as 1-kw. input. The motor-generator is designed to operate from 120-volt, direct-current mains and supplies a 500-cycle alternating current at 180 volts. The generator is of the inductor type, having no moving

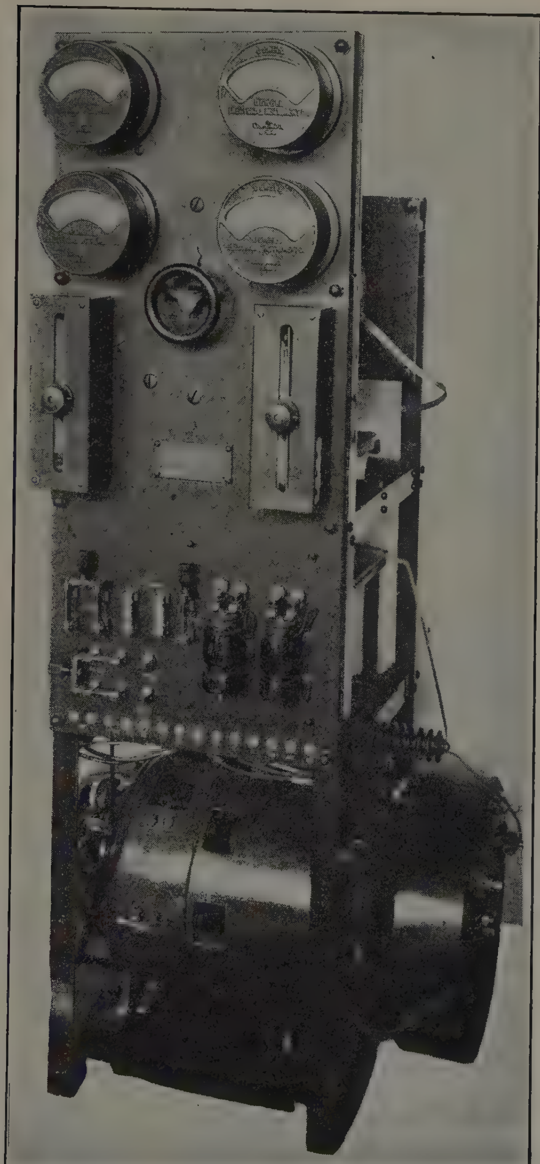


Fig. 182.—Independent spark transmitter.

coils, but a rotary iron-toothed inductor which periodically varies the magnetic flux between the stationary field and armature windings. The motor is accelerated to its normal speed within a short interval of time by a two-step automatic starter (Fig. 181). It will be noted that after the direct-current circuit is opened, the motor-generator may be brought to a stop very quickly by connecting a dynamic brake resistor across the alternating-current line. This is accomplished by means of a snap switch. The resistor tends to consume electric energy, but

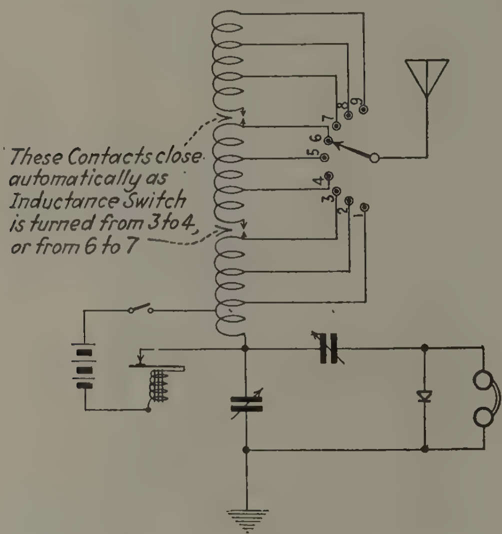


Fig. 183.—Schematic circuit diagram independent receiver, type A-1.

since it is no longer being converted from the mechanical form by the motor, the machine is brought to a quick stop.

A non-leakage, closed-core transformer steps up the voltage to a value sufficient properly to charge the antenna capacity formed by the antenna and ground. As the charging current reaches a maximum value in either direction, a spark discharge takes place, thus setting up oscillations in the antenna circuit. A short-wave, Dubilier condenser (mica dielectric) is provided to make possible transmission on 300 m. with the average ship's aerial. With some aerials it is also necessary to employ a short-wave condenser to transmit on 600-m. wave length.

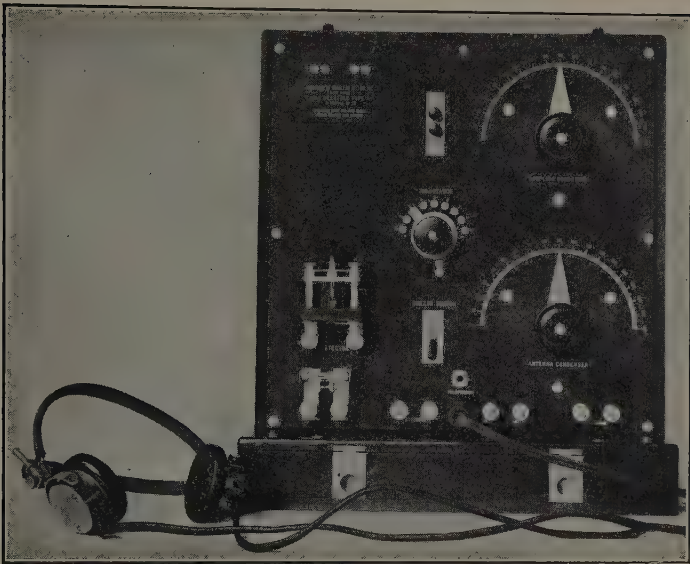


FIG. 184*a*.—Independent receiver, type A-1.

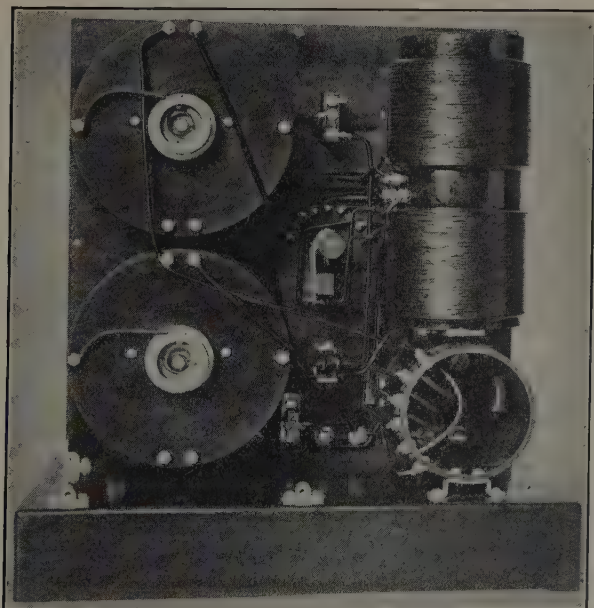


FIG. 184*b*.—Independent receiver, type A-1.

The wave-changing switch is of simple design and automatically changes the value of the inductance in series with the antenna circuit, as well as introduces the correct amount of capacity (short-wave condenser) in series with the circuit.

Among the standard accessories furnished are alternating-current and direct-current voltmeters, alternating-current ammeter, aerial ammeter, motor and generator rheostats, reactance regulator, protective condensers, etc. The complete transmitter is illustrated in Fig. 182.

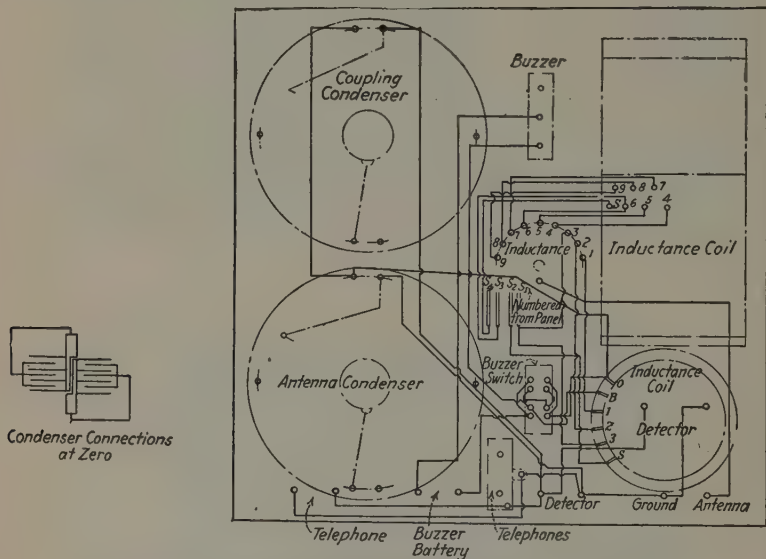


FIG. 185.—Complete wiring diagram independent type A-1 receiver.

The receiver is as simple as the transmitter. It consists, essentially, of a variable inductance divided into three sections so arranged that either one, two, or three sections may be employed (Fig. 183). If it is necessary to use more than a single section because of the particular wave length being received, a second section is automatically connected in the circuit as the inductance switch is turned to contact 4. If more inductance is required than that obtained when using two sections of the coil, the third section may be automatically made active by turning the inductance switch to contact 7. In addition, taps are taken

off intermediate points to each section and brought to contacts 1, 2, 3, 5, 6, 8 and 9, so that closer regulation of the inductance, as

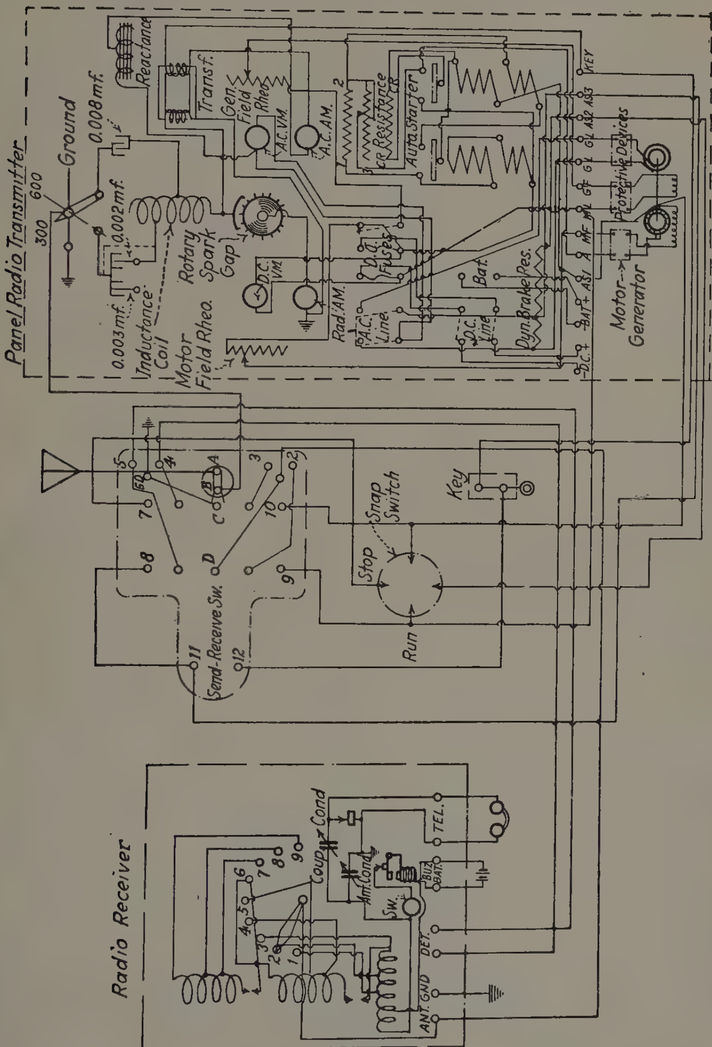


FIG. 186.—Complete wiring diagram Independent transmitter and receiver.

a whole, can be secured. A variable condenser is also provided in the antenna circuit so that very fine adjustments of the wave length can be made.

Coupling between the detector circuit and the antenna circuit is accomplished by means of a variable condenser. The lower the capacity of the coupling condenser, the looser will be the coupling between the two circuits; and vice versa, the greater the capacity, the closer or tighter the coupling. A buzzer circuit is also furnished so that the crystal detector can be readily adjusted to maximum sensitivity.

A suitable transfer switch is, of course, provided to connect the antenna to the transmitter or receiver as may be necessary.

Figure 184*a-b* show the panel arrangement and rear view of the Independent capacitively coupled receiver, type A-1. The complete wiring diagram of this receiver is illustrated in Fig. 185.

A complete diagram of the automatic starter, transmitting system, receiver, and aerial change-over switch is illustrated in Fig. 186.

THE CUTTING AND WASHINGTON IMPACT EXCITATION TRANSMITTER

The Cutting and Washington transmitter comes under that class of transmitters employing impulse excitation of the radiating circuit, and it also employs a quenched gap. It has, however, the following peculiarity: Across the high-tension side of the transformer, *i.e.*, in parallel with the quenched spark gap, is connected a circuit called the "concentration circuit," made up of a resistance, an inductance, and a capacity in series (see Fig. 187). The action of this concentration circuit is apparently somewhat analogous to that of a *surge tank* in a hydraulic pipe line. When the voltage is increasing in the high-tension circuit of the transformer the condenser of the closed oscillatory circuit is being charged, this taking place at a very low rate (500-cycle power is used in this case) compared to the natural period of the oscillatory circuit itself. When the voltage has reached a certain value, a spark jumps across the gap, and if the gap setting is right, a single *kick* will be given to the radiating circuit before the spark is quenched.

When quenching occurs, it appears that after a very small interval of time, depending upon the constants of the concentration circuit, another spark jumps the gap and the events are repeated, the concentration circuit discharging through the gap

circuit the energy which it has accumulated during the period of the preceding spark and the time just following. The result is that instead of a single spark occurring for each alternation of the power supply there actually are several wave trains set up during the time of one alternation. In this type of circuit, the great problem, aside from the adjustment of the quenched gap, is to get the proper adjustment for the concentration circuit. When properly balanced, it will cause the discharges to take place evenly during the active portion of each alternation,

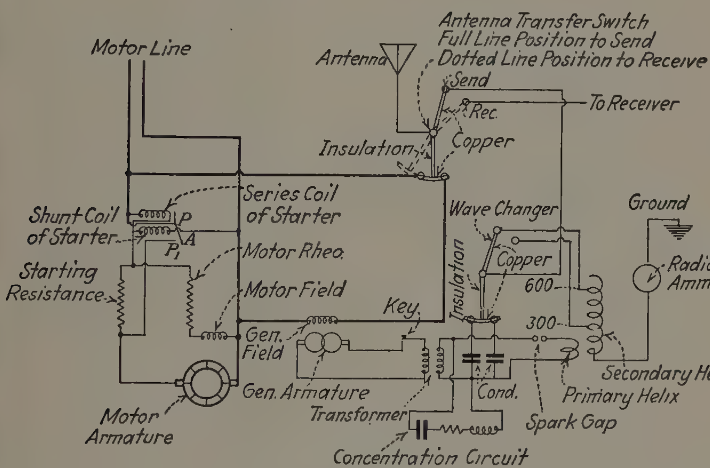


FIG. 187.—Elementary diagram Cutting and Washington type 4A transmitter.

and at the same relative places in all succeeding alternations, with the result that the transmitter radiates a smooth wave and produces a clear musical tone in the receivers. Unless this point is reached, however, the action of the circuit is unsatisfactory, and the spark tone is ragged. Some of the older Cutting and Washington sets were not equipped with the concentration circuit, but instead were equipped with special motor generator sets. These outfits may be recognized by the fact that they are not equipped with a control panel and the generator runs at a speed of 3,600 r.p.m.

The closed oscillatory circuit which has been considered here has a high damping, which is obtained by the use of a condenser of large capacitance and a very small value of inductance as the

primary of the oscillation transformer. In connection with this a multiple-gap quenched gap, having very small intervals (0.002″ per gap), and made from a special non-arcing material is used. When the gap is properly adjusted, the damping of the circuit is so high that quenching occurs after one-half cycle is completed. This also permits a very close coupling between the closed and the open oscillatory circuits, resulting in a high degree of efficiency in the transfer of energy from one of the circuits to the other.

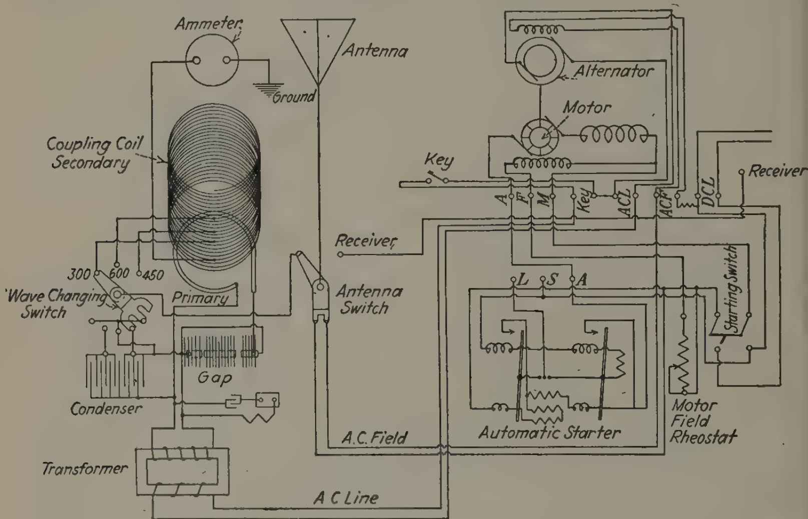


Fig. 188.—Complete circuit diagram Cutting and Washington ½-kw. transmitter.

When the actual series of events which thus take place during an alternation of the power supply have been considered the advantage of this multiple spark system will be seen. With one spark per alternation there would be but one kick given to the radiating circuit, and the oscillations in this circuit would die out at a rate depending upon the decrement of the antenna circuit. With the system under discussion, the amplitude of the antenna oscillations do not have an opportunity to fall off very much before a new kick, timed by the concentration circuit to be in exact synchronism, brings it back to the original value. The net result of this is to increase the effective value of the radiated energy for a given value of power input.

Theoretically, there is no reason for having any definite relation between the natural periods of the open and the closed oscillatory circuits, but from the practical standpoint it has been found that best results are obtained when the natural period of the closed circuit is maintained at about one and three-tenths times that of the open circuit. This means that when the wave length of the transmitter is changed, it is necessary to change the settings of the closed circuits as well; and this result generally is obtained by a change in the condenser capacity. The adjustment is not at all critical, however, and can be changed considerably without much change in the efficiency of the set. Figure 188 illustrates the wiring diagram of the ½-kw. type.

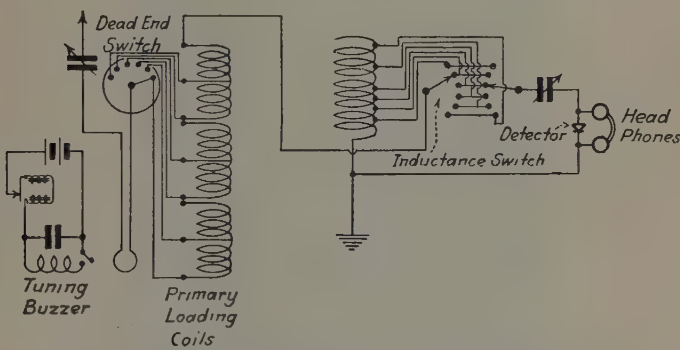


Fig. 189.—Circuit diagram Cutting and Washington receiver.

Figure 189 shows the Cutting and Washington receiving circuit. This is of the single circuit type, and the antenna circuit is made up of a variable condenser, a loading coil (controlled by a dead-end switch to cut out of circuit the unused portions of the coil) and a tuning inductance of rather large diameter, made up of copper strip, wound edgeways. This latter, by reason of its connection, acts also as the inductance in the detector circuit. The number of its turns included in each of these two circuits is controlled by two multipoint rotary switches, one for each circuit. The detector circuit is shunted to the coil, as shown, in series with a variable condenser for tuning. This condenser is valuable for cutting down interference and its capacity is decreased as the selectivity of the set increases. Of course, a

decrease in the capacity changes the natural frequency of the circuit and makes necessary an increase in the value of the inductance in the circuit to bring it back to the desired wave length.

FIG. 190a.—Cutting and Washington ½-kw. transmitter.

The condenser in question generally is used at settings between half-scale and full-scale only.

This receiving set often is fitted with a vacuum-tube detector in addition to the crystal detector. In that case, for vacuum tube reception the connection which in the diagram leads from the

variable condenser to the crystal would be connected to the grid terminal of the tube through the grid condenser and leak, and the

FIG. 190b.—Cutting and Washington 2-kw. transmitter.

ground connection would be run either to the positive or to the negative filament terminal, according to the type of tube used.

Note that with the ordinary ship's antenna, the tuning coil of the receiving set will enable you to work up to about 1,000 m. For waves about that length. use the loading coils, throwing in

the proper inductance value by means of the rotary *dead-end* switch mentioned before.

The operator throws from the receiving to the sending position by means of an antenna-transfer switch, shown in the general diagram. The knife blades of the control switches are mounted on two shafts which can be operated independently or together by a mechanism in the control handle. By this means the set

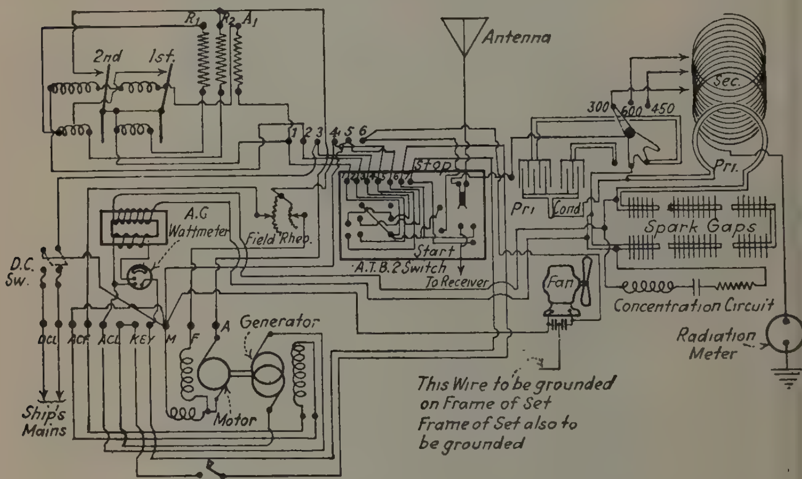


FIG. 191.—Cutting and Washington 2-kw. transmitter circuit diagram.

may be thrown from receiving to sending position with one movement of the handle, or by disengaging the clutch mechanism the motor-generator may be started while the operator is receiving.

The set briefly described above is made in three sizes, the ½ kw., 1 kw., and 2 kw. On the whole it is a very simple set to operate.

Figures 190*a* and *b* illustrate the panel arrangement of the ½- and 1-kw. type. Figure 191 illustrates the wiring diagram of the 2-kw. type.

NAVY STANDARD 1-KW. SPARK TRANSMITTER

Fig. 192*a* illustrates the complete installation of the Navy standard transmitter and receiver. Figure 192*b* illustrates the complete wiring diagram of the Navy Standard 1-kw. transmitter.

Practical Operation:

1. Throw the D. P. D. T. switch marked *radio* to either ship's power or battery. If the latter is used make sure that the four-pole switch is in *discharge* position.

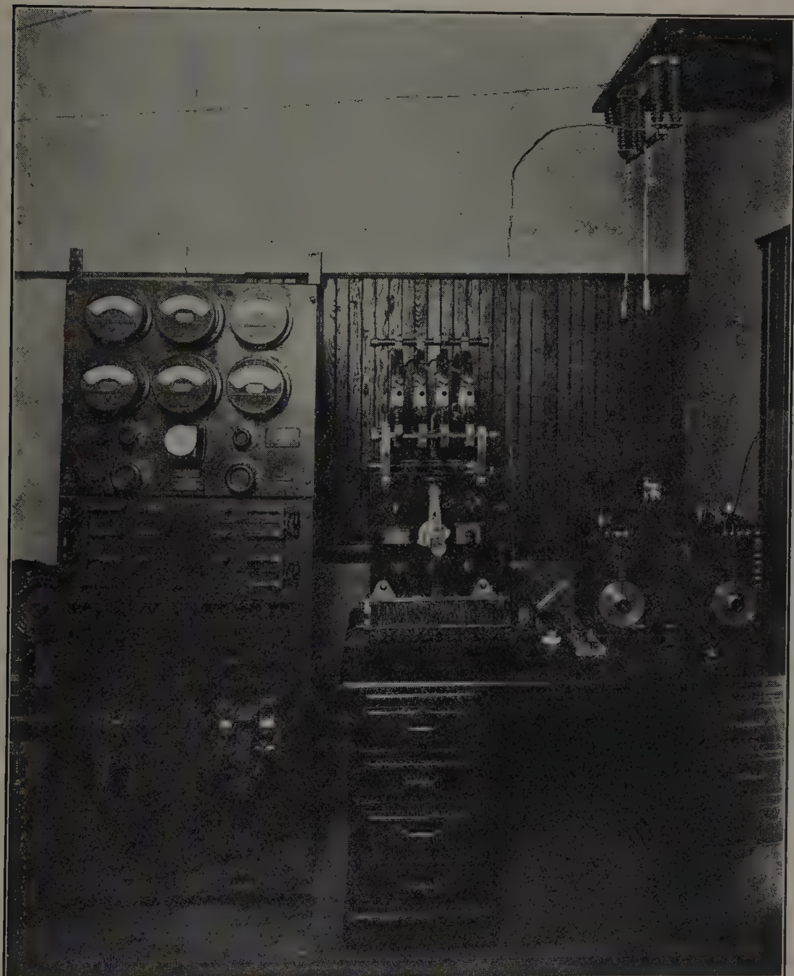


FIG. 192*a*.—Navy standard 1-kw. spark transmitter with S.E. 143 receiver.

2. Close the *auxiliary switch* on the right-hand side of the panel. This is connected in series with the aerial change-over switch generator field terminals.

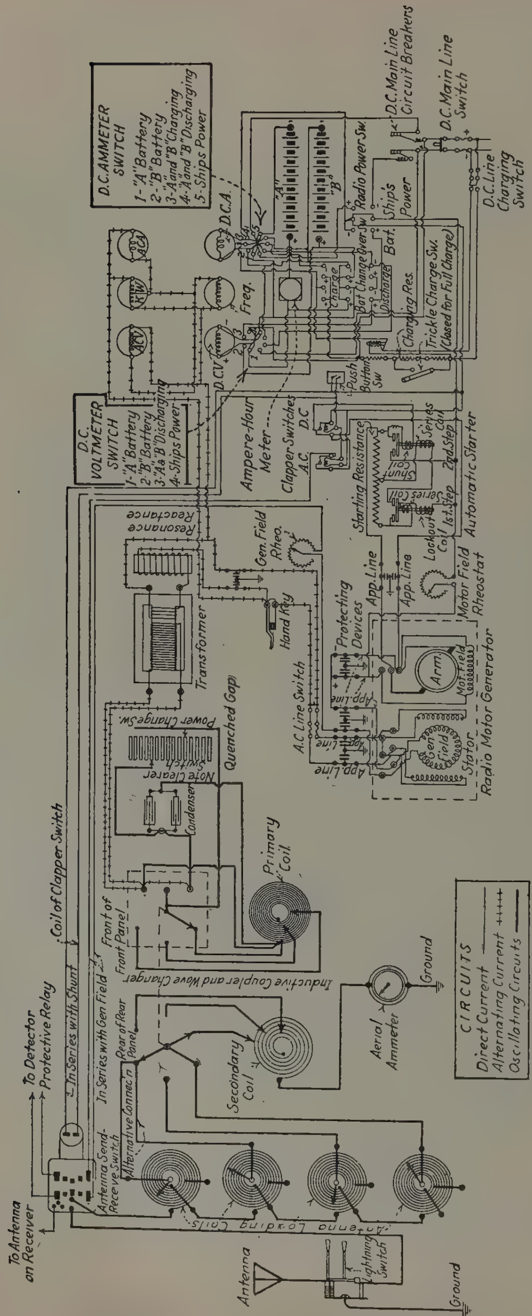


FIG. 192b.—Navy standard 1-kw. spark transmitter circuit diagram.

3. Close the two overload circuit breakers located at the lower right-hand side of the panel.

4. Throw the *antenna change-over* switch into transmitting position. This operation completes the energizing circuit for the double-clapper switch located at the lower right-hand end of the panel which in turn closes the generator-field excitation circuit.

5. Close the alternating-current switch.

6. Close the motor-starter snap switch or push button. This closes the direct-current clapper switch in the lower center portion of the panel and allows the current to flow through the armature-starter resistances and starting solenoids. After approximately 5 sec. the right-hand plunger of the starter solenoid will rise and short-circuit one of the starting resistances. After another 5 sec. the left-hand plunger will rise to cut out both of the starting resistances and allow the motor to run at full speed.

7. Regulate the *motor-field rheostat* until the frequency meter indicates 500 cycles.

8. Adjust the *generator field rheostat* so that the alternating-current voltmeter reads approximately 250 volts.

9. Cut in about three-quarters of the quenched gap section.

10. Throw the *wave-changing switch* to the desired wave length. This automatically adjusts the primary and secondary inductances to their proper points for the respective wave lengths.

The coupling may be varied slightly for maximum radiation at each change of the wave length due to a possible change in the coupling coefficient. However, in most instances this has been compensated for by the inspector when tuning and should not be changed if satisfactory radiation is obtained at each wave length.

11. Press the key and note the radiation on the antenna ammeter.

12. If the reading is too low, increase the power by decreasing the generator field resistance at the generator field rheostat and increase the number of gaps to maximum.

One of the main troubles encountered with this transmitter is the plunger adjustment of the automatic starter. This may be properly adjusted for the correct time period by varying the thumb screw at the bottom of the solenoids until each plunger rises at the proper time.

NAVY STANDARD RECEIVER TYPE SE143 WAVE LENGTH RANGE 250 TO 3,100 METERS

Practical Operation. Stand-by Tuning.—Set the *tuned untuned knob* on the *untuned* side. Adjust the inductive coupler to approximately 100 deg. Set the stopping condenser at its

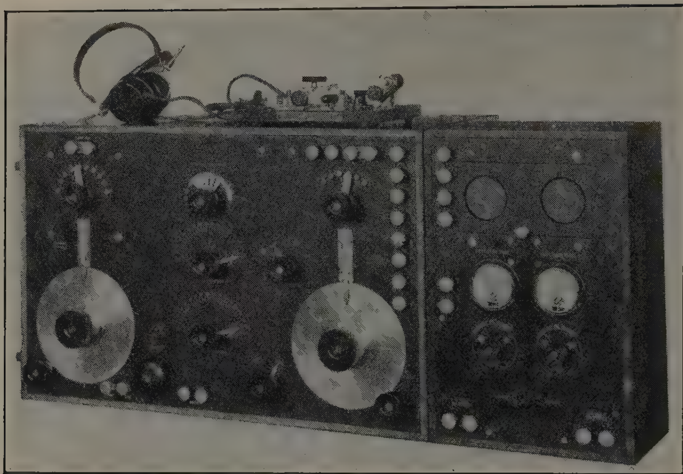


FIG. 193.—Navy standard S.E. 143 tuner with detector and one stage amplifier.

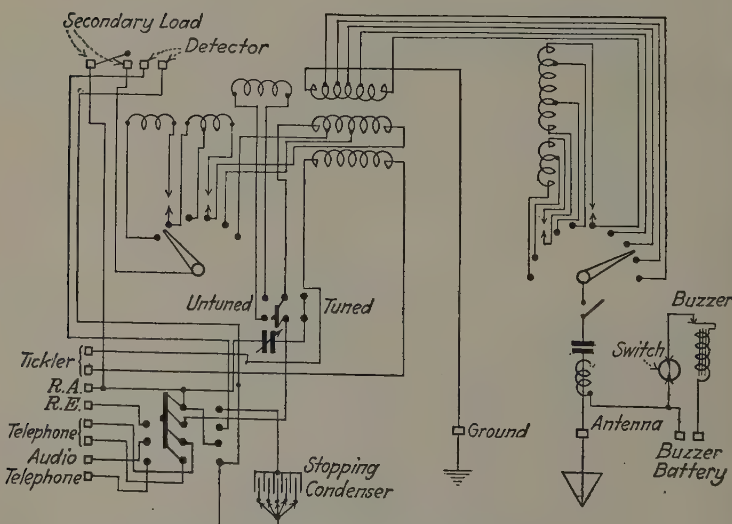


FIG. 194.—Navy standard S.E. 143 tuner circuit diragam.

maximum value. Then vary the primary condenser and inductance until a maximum signal is heard. (Fig. 193.)

Selective Tuning Adjustment.—Throw the *tuned untuned switch* to *tuned* side, and adjust the secondary capacity and inductance for the maximum signal. The sharpest tuning with this adjustment is best obtained by cutting the stopping condenser out of the circuit and placing the coupling pointer at approximately 30 deg. For additional information on the tuning of this receiver refer to IP501 receiver which is closely related.

Additional Information.—This receiver is usually used with an external vacuum-tube arrangement and in this case proper care must be taken in connecting the tube circuit to the receiver.

Operation with Vacuum Tube.—Set the stopping condenser so that about half the capacity is in use. Set the tickler at about 90 deg., raise the filament current to 5 volts adjust the tuning control of the antenna and secondary circuits to the desired wave length.

Probable Troubles.

1. *Failure to Oscillate:*
   a. Improper tickler adjustment
   b. Reversed tickler leads.
   c. Reversed B battery leads.
   d. No by-passing condenser across the telephones.
   e. Defective tube. Loose connections.

Care.—1. Make sure that all binding posts make good contact with the leads.

2. Scrape wires at the point of contact.
3. Clean switch blades. Tighten the switch arms.
4. Keep the panel and all parts in a polished condition.

R.C.A. TYPE IP501 AND 501A RECEIVER

The types 501 and 501*A* are the well-known Navy standard types of receivers in many ways similar to the type SE143 receiver previously explained. These receivers are primarily designed for vacuum-tube reception, but provision is made for a crystal detector. These receivers have a wave-length range of from

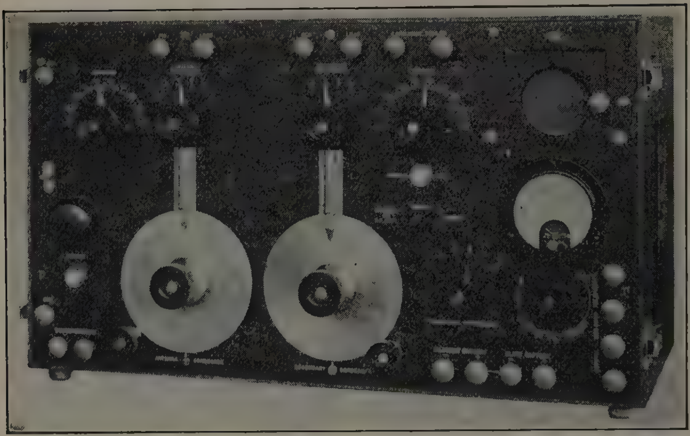


FIG. 195.—R.C.A. IP501 receiver

FIG. 196.—Two-stage amplifier for IP501 receiver.

250 to 8,000 m., and possess a high degree of sensitivity and selectivity over the entire band.

Figure 195 shows the panel arrangement of the IP501 receiver which contains a single tube for detection. Most of these receivers, however, are equipped with a two-stage audio frequency amplifier cabinet as in Fig. 196.

The later model, type IP501A, is exactly the same as the IP501A illustrated, with the exception that the detector and two stages of audio amplification are all in one cabinet, as shown in Fig. 197. Figure 198 shows the interior arrangement of this model.

The practical operation of both receivers is the same.

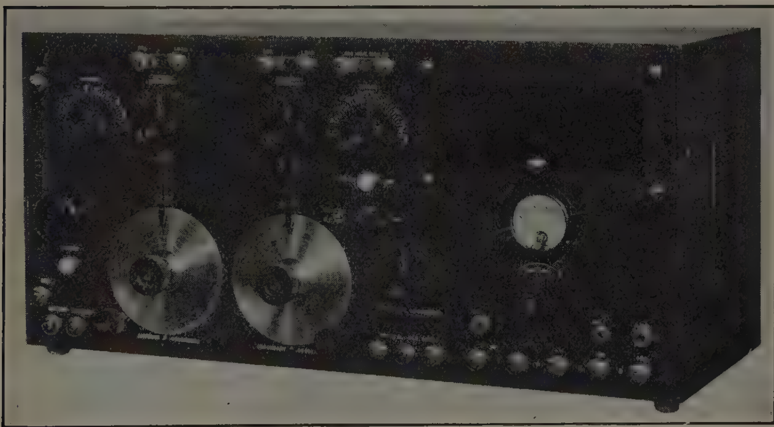


FIG. 197.—R.C.A. IP501A receiver (front).

Practical Operation.—In using these receivers with a crystal detector throw the cam switch to the left. Connect the crystal detector stand to the terminals marked accordingly. Connect the telephones to their respective binding posts. The buzzer should then be placed in operation by pressing the buzzer button. Adjust the crystal to a point of maximum sensitivity. Place the *coupling knob* at 180 deg. on the dial. Make sure that the antenna and ground connections are made and also that the small safety gap across the antenna binding posts is not short-circuiting the posts. Place the dials of the condensers at zero and commence increasing the antenna and secondary inductance switches to the inductance approximating the desired wave. The

secondary and antenna condensers are then varied for a sharper signal. If it is found that the tuning is broad, however, readjust the *coupling knob* to about 100 deg. and then again carefully adjust with the secondary and antenna condensers. This is simply a matter of experience, and the operator will find these tuners extremely simple to operate after a few days of use. In receiving wave lengths below 8,000 m., the three pairs of binding posts on the top of the panel marked *load* should be short-circuited. These posts are only used when the receivers are accompanied by a standard long-wave attachment placed on top of the tuners.

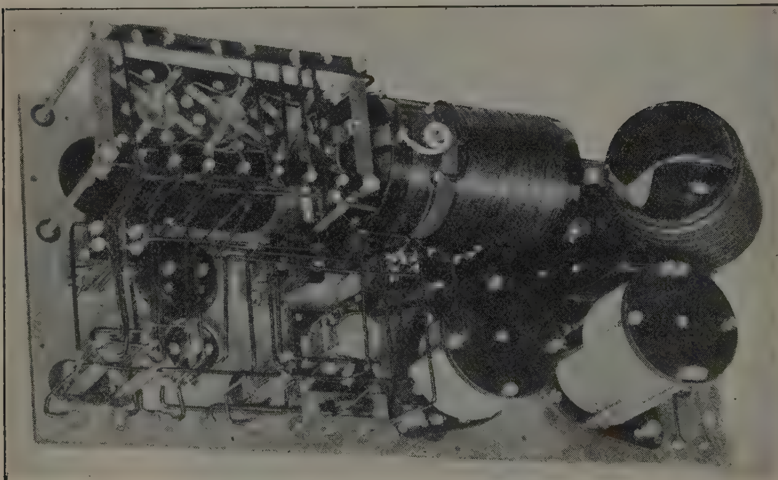


FIG. 198.—R.C.A. IP501A receiver (rear).

This long-wave attachment has six binding posts suitably marked and are used for loading primary, secondary and tickler circuits to waves above 8,000 to 20,000. (Fig. 199.)

If the vacuum-tube detector is to be used, then throw the cam switch to the right. Turn the rheostat handle in the direction marked *increase filament current,* until the filament voltmeter reads 5 volts. If the tuner is now to be adjusted for spark reception the *tickler knob* should be set at approximately 120 deg.

Vary the antenna and secondary inductances and condensers until a maximum signal is heard. Then resonate for a maximum signal by carefully adjusting the secondary and antenna condens-

ors critically. Adjust the *telephone condenser knob* until the signal is maximum. Then, for sharp tuning, loosen the coupling by varying the *coupling knob* to approximately 100 deg.; then carefully resonate the antenna and secondary circuits again by the vernier adjustments on both aerial and secondary condensers.

For the reception of continuous waves, it will be necessary to loosen the tickler coupling as much as possible. Loosen the coupling between the primary and secondary circuits by the *coupling knob* and then tune the primary and secondary circuits in the same manner as before. It may be suggested here that, when the tube is oscillating, a slight click will be heard as the condenser passes through resonance. The best tone will be obtained when the setting is slightly above or below the resonant point.

Oscillation may be determined by pressing the button marked *oscillation test* and if a click is heard the receiver is oscillating. If the circuits are resonated and no click is heard then vary the *tickler knob* either way, depending upon the station, until the desired effect is obtained.

Troubles and Remedies:

1. *Failure to Oscillate:*
   - *a.* Plate battery reversed.
   - *b.* Improper tickler adjustment.
2. *Distorted Spark Signals:*
   - *a.* Plate potential too high.
   - *b.* Improper tickler adjustment.
3. *Squealing or Hissing Noises:*
   - *a.* Soft detector tube.
   - *b.* Filament rheostat too high.
   - *c.* Improper tickler adjustment.
   - *d.* Defective grid condenser.
   - *e.* Poor connections.

The complete wiring diagram of the tuning devices and detector tube is illustrated in Figs. 199 and 200.

Questions

1. Describe the Independent type, B1 spark transmitter.
2. Describe the Independent type, A1 capacitively coupled receiver.
3. Give a circuit diagram of the AI receiver and explain its operation.

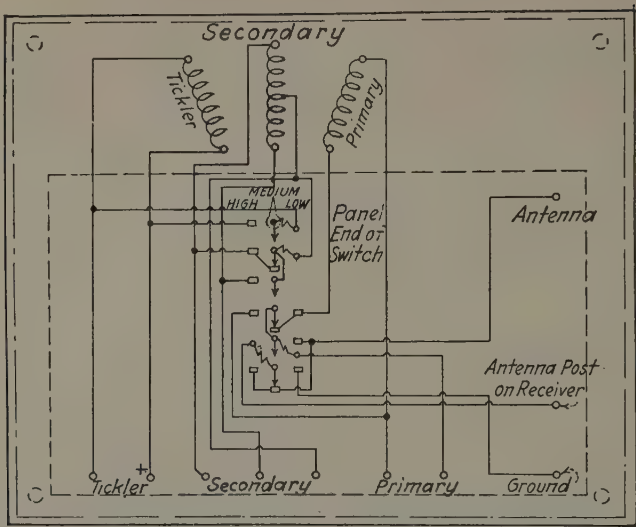


FIG. 199.—R.C.A. long wave attachment for IP501 receiver.

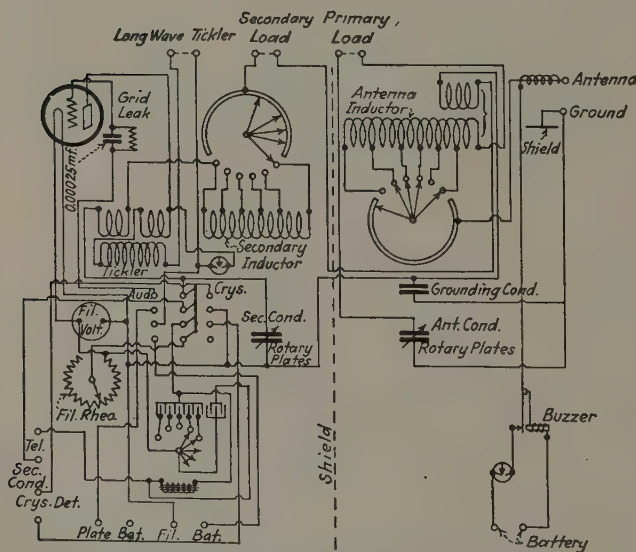


FIG. 200.—R.C.A. 501 receiver, circuit diagram.

4. Explain how to place the Navy standard 1-kw. transmitter into operation.

5. Describe the practical operation of the S.E.143 receiver.

6. Describe fully the practical operation of the Radio Corporation of America types IP501 and 501A receivers.

7. Draw diagram of the IP501 receiver.

8. If the receiver failed to oscillate where would the trouble be?

9. What might cause squealing or hissing noises?

10. What is the cause of distorted spark signals?

CHAPTER XXIV

THE RADIO COMPASS

Purpose.—The radio compass makes it possible to determine almost the exact direction from which a radio signal is coming. It is used to determine the relative bearing of an incoming signal to the receiving station.

Before the invention of the radio compass the navigator of a ship had to depend on light and sound signals for position determination. Both light and sound are extremely unreliable, especially in foggy weather, due to the inability of light to penetrate fog for more than a very short distance and the inaccuracy of the human ear in detecting a horn, whistle, or other sound device in other than clear weather.

Countless shipwrecks, thousands of lives and millions of dollars lost may be credited to the absence of a device which would record accurately the source of a given signal.

During the World War it was especially desirable to locate enemy radio stations, and it was to this use that the radio compass was first put. Since the war the radio compass has been applied to commercial pursuits, the merchant marine, and aviation. The model described in this text and shown in Fig. 218 is a standard model for merchant ships. Special types have been developed for aviation but as this field is limited under present conditions discussion of these types is omitted.

Fundamental Principle.—In the discussion of aerials in a previous chapter, it was stated that a directional effect was noticeable in all aerials. This is true with all except the vertical-wire type which is equally affected by all signals regardless of direction. The inverted L and the T types of aerial must be erected with the directional effect in mind.

The loop aerial, as shown in Fig. 218, shows a directional effect more than any other type. This is logical when the action underlying the generation of current in a wire is considered.

When a wire is cut by lines of force, a current is generated therein. It is this principle, underlying nearly all electrical machinery, which must be held clearly in mind.

A vertical wire aerial forms an aerial which is entirely symmetrical to radio waves traveling horizontally; such a wire has no directional effect. If a sensitive indicating instrument is connected to measure the current intensity in such a wire it will indicate like values for all signals. It makes no difference whether they originate in the east, west, north, or south, presuming, of course, that the power of the transmitting station is the same in each direction.

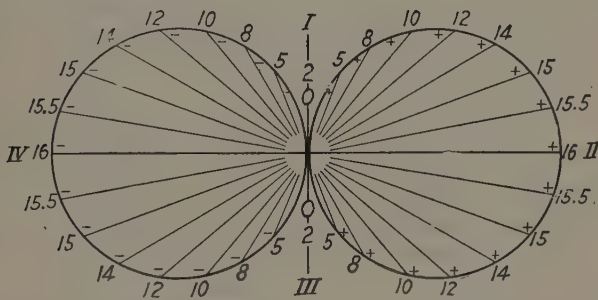


FIG. 201.—Bilateral characteristic. II and IV. At this point the loop is in a plane parallel to the direction of the transmitting station. I and III. At this point the loop is in a plane at right angles to the direction of the transmitting station.

Bilateral Characteristics.—If a similar indicating instrument is connected so as to measure the current intensity in a loop, a graphic representation of the current value flowing in the loop, as it is rotated through 360 degrees, would make a figure-of-eight (8) characteristic, as shown in Fig. 201. The heavy lines radiating from the center O to the curve show relatively the current values. This is called a bilateral characteristic.

Starting at point I when the plane of the loop is at right angles to the direction of the transmitting station, the curve shows zero current. This is due to the way in which the loop wires are cut when the coil is in this position.

An analysis shows that a current is set up in the loop as shown by the arrows in Fig. 202. By applying the right-hand rule explained in Chap. III it is seen that the current would take the

direction indicated, assuming that the reader is in the position of the transmitting station. Furthermore, in view of the fact that the two sides of the loop in which the current is flowing clockwise is equal in length to the other two sides in which the current is flowing counterclockwise, the current in one-half of the loop bucks the current in the other half and the result is that there is no current flow. This is indicated by zero on the current curve.

Now turn the loop in a clockwise direction towards point II. It will be noticed that the signal which registered zero in the first instance now increases in intensity and the current meter, which should be a zero-center instrument, as shown in Fig. 203, begins to register a current flow in the positive (+) direction. This is due to one side of the loop, which we may call the *c* side (see

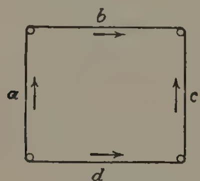


Fig. 202.

Fig. 203.

(Fig. 202) coming nearer to the transmitter and side *a* moving farther away from the transmitting station. The result is that the signal strikes side *c* first, and side *a* last, causing a phase difference in the e.m.f.'s generated and a current flow in the loop which registers on the meter. The current value increases from zero value at point I, which may be called "north," to a value of 16 units at point II, which may be called "east." Notice that the angle of rotation necessary to cause a rise in current value from 0 to 5 is much less than the angle through which the loop must be turned to increase the current value from 10 to 15, although the current increase is the same in both cases. It is less difficult, therefore, to find the position of minimum than maximum current when headphones are used instead of a current meter as is the case in practical types of radio compasses.

As the rotation of the loop is continued towards point III, south, it is seen that the current decreases again to zero. The

loop has now been turned completely around, 180 deg. A minimum signal is again obtained.

It is to be remembered that thus far all current has flown in one direction which, for the sake of designation, will be called positive. It rose from 0 to 16 (maximum) and then decreased again to 0.

From point III, the rotation is continued and here a change takes place. The current-indicating instrument begins to register but in the opposite, or negative, direction. The current has changed direction. The wires of the loop are being cut from their other side. Remember the fundamental right-hand rule—the direction of cutting determines the direction of current flow.

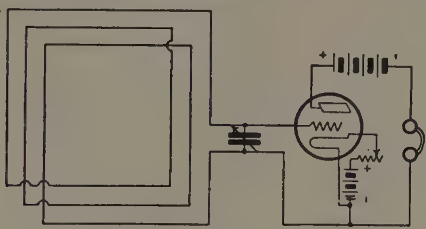


Fig. 204.—Simple radio compass

Exactly the same phenomenon takes place from 180 to 360 deg. as took place during the first half, 0 to 180, except that the direction of current flow is negative—the reverse of positive.

It is seen then that at point IV, west, the current value is the same as at point II, east and, further, that as point I, north, is approached, the current value decreases toward zero making the values at north and south equal.

We now have a characteristic curve in the shape of a figure of eight (8). In practice, this theoretical curve may be somewhat unsymmetrical but, fundamentally, it follows the figure-of-eight (8) characteristic.

From the above it is understood that the line of direction in which a transmitting station lies may be determined by using a loop and a detector (vacuum tube) and headphones. This simple direction finder may be connected up as shown in Fig. 204. It cannot be ascertained, however, whether the signal comes from a given point or its reciprocal: *i.e.*, north or south; east or west, with such a circuit.

As an example of the operation of a direction finder, or radio compass, using the circuit shown in Fig. 204, which shows the line of direction only, and is not unidirectional in character, examine the illustration in Fig. 205. Suppose that the direction finder is located at point *A* and the transmitting source is on a ship at *B*; then the line of direction as indicated by the position of the loop when minimum signal is received is the dotted line which shows that the position of the transmitting station is in the line *AB* or *AC*. The radio-compass operator knows, however, that the transmitter is a ship station and, therefore, must lie towards the ocean side and not the land side; hence, the position must be in the lines *AB* and not *AC*. In the above case, a radio compass having undirectional characteristics is, for obvious reasons, unnecessary.

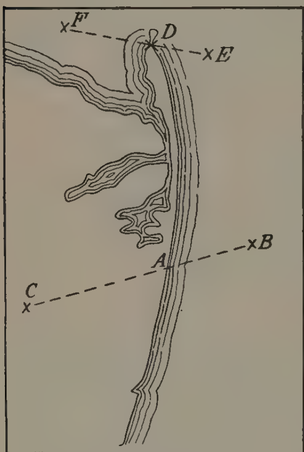


Fig. 205.

Suppose the direction finder is located at point *D* and the transmitting station is located on a ship at point *F*, then the line of direction as indicated by the position of the loop would be in the line *FE*. In this case, with a radio compass having no unidirectional characteristics, it would be impossible for the operator at *D* to determine whether the transmitting source was at *F* or *E*. To determine the exact direction it would be necessary to nullify the signal when the pointer which is attached to the loop pointed towards *E*. It is possible to do this by using a circuit having unidirectional characteristics. On shipboard such a circuit is absolutely necessary as, in most instances, there is the possibility of the transmitting source lying on either side of the loop. Unidirectional characteristics enable the operator, or navigating officer, or whoever may be taking a reading of the radio compass, to tell the true direction.

Unilateral Characteristics.—Assuming that no form of loop or other antenna is used, and that signals are received by direct action through earth capacities, the current curve for signal intens-

ity from various directions would take the form of a circle as shown in Fig. 206. Notice that the polarity of the current remains constant regardless of direction. Such a curve is also the characteristic of a vertical-wire aerial. As an example, assume that the receiver is located on an island and that the transmitter is a ship which completely encircles the island. The intensity of the signal when the ship is north is the same as when it is to the south, east or west of the island.

Utilizing this symmetrical current-curve characteristic when receiving through earth capacities only, in connection with the figure-of-eight (8) characteristic of the loop, it is possible to get a theoretical resultant curve as shown in Fig. 207. In practice, the signal may not be entirely nullified when the loop pointer points in a direction opposite to the true direction. In other words, a signal may still be heard and the characteristic curve may take the form shown in Fig. 208. Notice, however, that the loudest signal, or largest current flow, is unidirectional and that the loop must be turned in the proper position for this signal. There are two points of silence or minimum signal with this system, just the same as when using the coil alone. These points of silence are still used to determine the direction; but the side from which the signals are coming is determined by coupling to the detector circuit both the loop figure-of-eight current curve and the circular current curve, with a result as shown in Fig. 207, and this is done by connecting the apparatus as shown in Fig. 209.

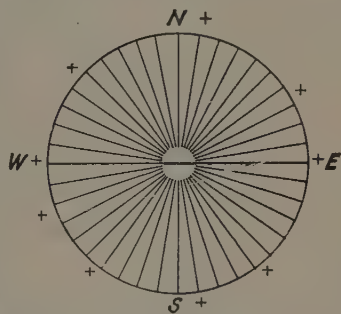


Fig. 206.—Single wire vertical antenna or earth capacitance characteristic.

An analysis of these combined characteristics shows just why the signals are strong from one side and weak from the other. In this analysis, it must be borne in mind that the circular curve, which is positive in all directions, is the current resulting from the earth capacitance, while the figure-of-eight curve is that of the loop current when the loop is rotated through 360 deg. The resultant curve which, theoretically, may take a heart shape (Fig. 207) is called a cardioid characteristic, meaning "heart shaped."

Now, to go on with the analysis, when the loop-current curve is negative, it is bucked by the positive current from the earth capacitance and the current in the headphones or current meter

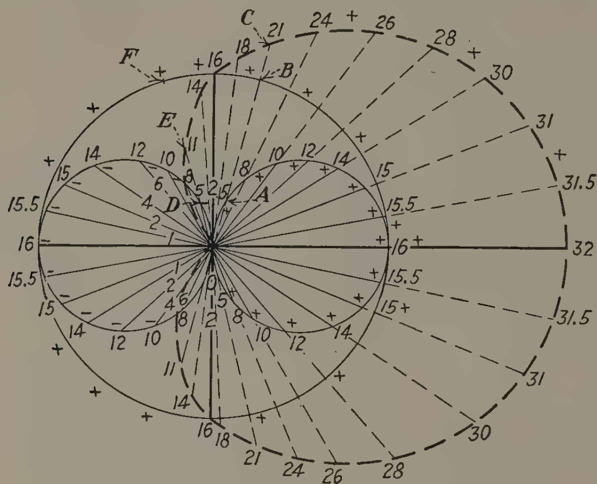


FIG. 207.—Unilateral or cardioid characteristic.

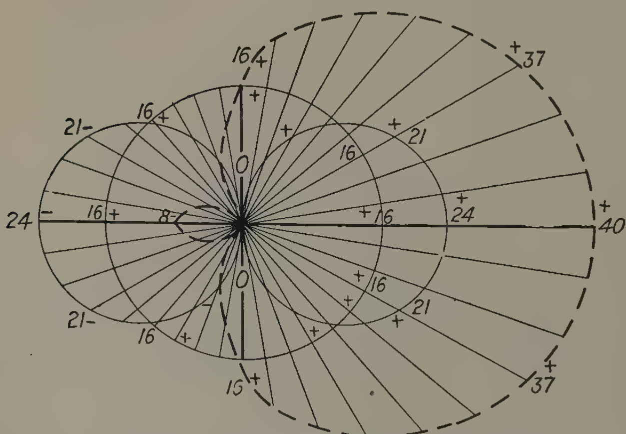


FIG. 208.—A non-perfect cardioid characteristic.

is minimum: likewise when the loop-current curve is positive, it is augmented by the earth capacitance positive-current curve and the sum of the two currents is the resultant. The heavy dotted-

line curve indicates the resultant strength of the current in the current meter or headphones and this is called the "unilateral" or "cardioid" (heart) characteristic.

To take specific points on the curves, examine point A on the figure-of-eight curve which reads 5+; this added to the 16+ (point B) of the circular earth-capacitance curve gives the cardioid curve a value of 5 + 16 which is 21. This is the value at point C. In the above case, both the loop curve and the earth curve were positive. This resulted in one value augmenting the other.

Another result is obtained when the polarity of the curves differ as at points D and F. Here the loop curve is 5− (point D), and the earth curve 16+ (point F), which results in a cardioid curve of 11+ (point E), the result of adding 5− to 16+.

A close study of the cardioid curve will show that it is the result of adding the loop curve to the earth curve values. It is obvious, from the above explanation, that the strength of the received signal, using the circuit shown in Fig. 209, is entirely dependent for its value upon the position of the loop.

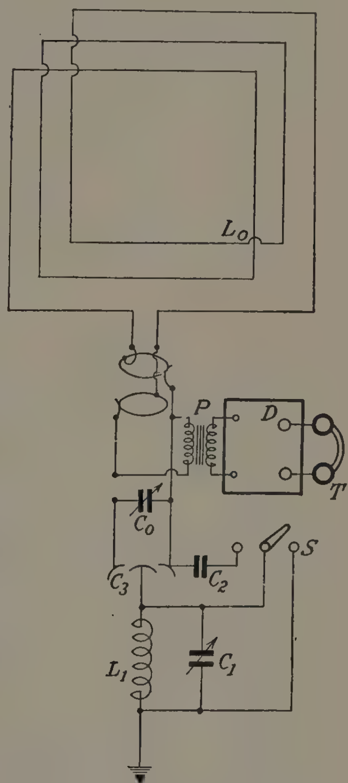


Fig. 209.—Standard radio compass circuit.

Operation.—To obtain a bearing on the radio compass the switch, S, is thrown to the right. This cuts out the earth capacity effect by short-circuiting the inductance L_1. The loop is rotated until a pointer which is set over a standard magnetic compass is over the point of minimum signal. In practical radio-compass installations headphones are used to determine signal intensity. The pointer indicates the true point of minimum signal or its reciprocal. In other words if the pointer reads 45 deg.; then

the other end of the pointer reads the reciprocal of 45 deg. which is 225 deg. The reciprocal of 0 deg. is 180 deg., of 20 deg. it is 200 deg., of 90 deg. it is 270 deg. on a 360-deg. circular scale.

The point of minimum signal indicates the true direction of the transmitting station or its reciprocal. The true position, if the pointer reads 45 deg., is either 45 deg. or 225 deg. The transmitting station lies in one of these directions.

The next operation is to determine which is the correct reading, or true direction, and this is simply done by throwing the switch S to the left. In this position the earth-capacitance coil acts on the loop either in a positive or a negative way. The loop is then rotated to the point of maximum signal intensity and this point will lie near one or the other of the points of silence obtained with the switch thrown to the right. This is the way in which the true direction is determined.

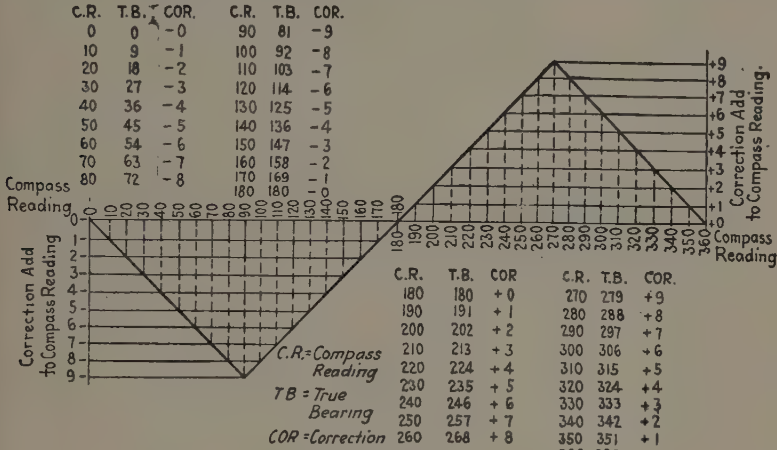
Example:

1. Switch S, to the right.
2. Minimum signals received at 45 and 225 deg.
3. Switch is then thrown to the left.
4. Maximum signal strength is heard on the 45-deg. side of the scale.
5. This indicates that 45 deg. is the bearing of the transmitting station from the radio compass.

Calibration.—The radio compass requires calibration just as does the ship's magnetic compass. By calibration is meant recording, the readings of the compass in comparison with true magnetic bearings. This may be done in two ways, as follows: the ship or shore station where the radio compass is located is encircled by a small boat carrying a radio transmitter. Signals are sent from various points around the radio compass to be calibrated and the readings recorded on a curve sheet as shown in Fig. 210. This is known as a *correction* or *error* curve. Another method which may be used to calibrate a radio compass installed on a ship is to take bearings from a given stationary radio transmitter such as a lightship or lighthouse and simultaneously take radio-compass bearings from the same point.

Correction Curve.—The calibration readings are plotted as a curve which shows the relationship of the radio-compass readings to the true magnetic bearing. This is known as a correction or

error curve; a sample of such a curve is shown in Fig. 210. This curve automatically provides any necessary correction factor.



C.R.	T.B.	COR.
0	0	−0
10	9	−1
20	18	−2
30	27	−3
40	36	−4
50	45	−5
60	54	−6
70	63	−7
80	72	−8
90	81	−9
100	92	−8
110	103	−7
120	114	−6
130	125	−5
140	136	−4
150	147	−3
160	158	−2
170	169	−1
180	180	−0
180	180	+0
190	191	+1
200	202	+2
210	213	+3
220	224	+4
230	235	+5
240	246	+6
250	257	+7
260	268	+8
270	279	+9
280	288	+8
290	297	+7
300	306	+6
310	315	+5
320	324	+4
330	333	+3
340	342	+2
350	351	+1
360	360	+0

Fig. 210.—Correction curve.

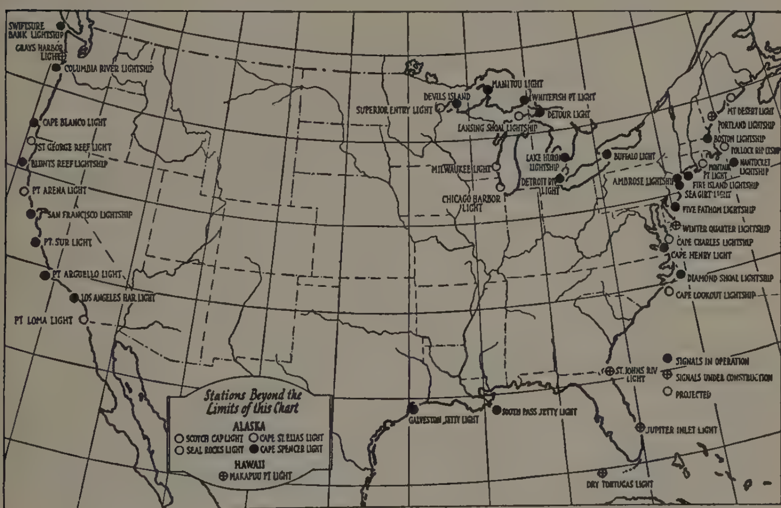


Fig. 211.—Radio fog signal stations.

The compass readings are plotted horizontally along the center line of the chart from 0 to 360 deg. and the correction factor is plotted vertically from 0 to 10+ and −. The correction factor

shown is to be added if + and subtracted if −. For example, in the chart in the figure, if the position indicated by the pointer on the radio compass indicated 50 the correction factor is −5, therefore, the true bearing is 45 deg.; if the pointer read 250 deg. then the correction factor is +7, therefore the true bearing 257 deg.

In modern types of radio compasses the correction is automatically made by a device, between the pointer and the loop, called a compensator.

RADIO CORPORATION OF AMERICA DIRECTION-FINDER TYPE AG1382: INSTRUCTION FOR CARE AND OPERATION

Ship's Antenna.—The ship's radio antenna must be *open* during the period when the radio compass is being used. In addition, the radio operator must carefully observe the surroundings of the *direction-finder* coil, for the purpose of eliminating accuracy losses in the compass readings due to stray halyards, whistle cords, tuned wires, or closed loops which may have sufficient length to approximate the natural period of the radio compass. This holds especially true in the case where these objects are insulated. In many cases, however, where the objects cannot be removed, there will obviously be a false directive position of the radio compass, and the only alternative in this case would be to determine carefully by calibration the discrepancy in the reading caused by the said objects, and then *grounding* each one of the obstructions.

The Receiver.—The radio receiver is of the superheterodyne type, totally shielded, employing eight radiotrons of the UX199 or CX299 types operated by a small storage battery which *must* always be kept on *trickle* charge when not in use. The plate potential is supplied by dry *B* batteries of the heavy-duty type. All of the batteries are contained in the bottom of the pedestal casting, the entire direction finder being self-contained in one unit, thereby making the complete equipment an extremely compact arrangement.

The wave-length range of this receiver covers a band of 550 to 1,050 m. In the majority of instances the 1,000-m. wave is used, thus making it extremely easy to operate the receiver after its initial performance.

Operation.—Note carefully the arrangement of the tuning controls on the receiver panel in Fig. 212 and refer to it freely during the following explanation:

Unlock the cover in front of the receiving panel and draw open. This automatically disconnects the "A" battery from trickle charge. Press the button marked *on* for lighting the filaments. (The cover automatically shuts off the filament battery and places it on trickle charge when closed.)

Insert the telephone plug into the jack on the right or the left-hand side of the panel. Two pairs of telephones may be used.

Adjust the filament voltage to the point marked 3 on the *filament voltmeter* by turning the *filament rheostat* to the right,

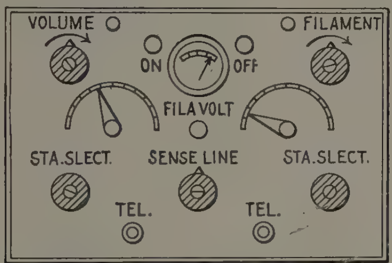


Fig. 212.—Panel arrangement on R.C.A. radio compass type AG1382.

first closing the filament voltmeter button. This reading will be found at approximately the half-way point on the rheostat.

Place the *sense-line* switch at *line*.

Turn the loop for a "maxima" in the approximate direction of the radio-beacon station.

Move the *station selector* pointers at the minimum end of the scale by turning their respective knobs.

Move simultaneously and slowly towards the maximum end of the scale until the desired station is heard. This station will always be found at the same points of the dial in future use.

Adjust the *volume knob* for the desired volume.

The loop should now be rotated until the signal diminishes to a minimum or *null* point. This requires considerable practice by the operator and, in some cases, it may take several days before *null* points are obtained with any degree of accurancy. Quite frequently it will be noted that this null point is very diffi-

cult to obtain, due to strong signals. In this case, adjust the volume control or compensating condenser for a weaker signal. The latter device, when used in a compass receiver, can be adjusted to a point where an extremely fine null point can be

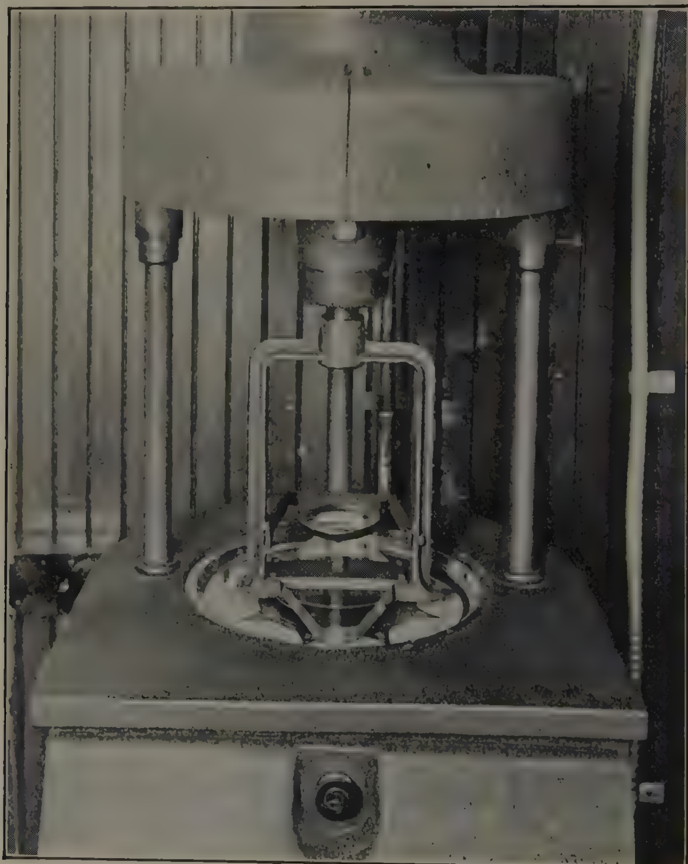


FIG. 213.—Compass bowl, R.C.A. radio compass.

obtained. It is being installed in practically all of the modern compass equipment.

After this null point has been finally found to be of a sharp characteristic, the degree reading on the gyro compass or "dummy" bowl are taken.

If the gyro compass is used make sure that the compass is adjusted at the same heading as the master gyro compass. This is accomplished by checking it with the watch officer. Then, if the gyro repeater is so headed all bearings taken thereafter are regarded as *true*.

If a "dummy" compass bowl is installed it should first be set on *zero*. All bearing taken thereafter will be so many degrees off the bow and will then have to be converted into *true* by one of the watch officers. However, if the gyro repeater has been cut out of the repeater circuit from the master compass through some mechanical defect, the gyro repeater should be set on *zero*. All bearing taken thereafter would be the same as the "dummy" compass reading—so many degrees off the bow.

Figure 213 illustrates the bowl arrangement of the Radio Corporation compass.

FAILURE OF THE RECEIVER TO OPERATE

Probable Faults.—Before proceeding to take off the panel, inspect very carefully all exterior connections of the receiver, such as the receiver cover, storage battery, and B batteries. These are in the most cases the outstanding troubles and can easily be repaired. Next in line of minor troubles are run down A or B batteries or deactivated tubes. The latter, in the majority of cases, is due to the negligence on the part of the operator in turning the *filament rheostat too far* to the right during the period that the A battery is in a fully charged condition. The remedy in either case is obvious and the defective tubes or B batteries should immediately be removed. If none of the above mentioned suggestions are met with favorable results, it will be necessary to examine the catacomb and then look for some of the following faults:

Some of the wax may have boiled out of the catacomb. This should not necessarily give rise to an interior short-circuit but would probably indicate a short-circuit in one of the tubes, such as touching elements, *i.e.*, grid to plate or plate to filament. This may result in the burning out of a transformer, primary or secondary, if not rectified in time.

In some instances, interchanging the tubes will help matters considerably if the trouble is found to be poor signal intensity.

It may be suggested here that, inasmuch as one of the tubes is doing double duty, such as the oscillator, detector tube (located second from the right), it might be replaced with one of the

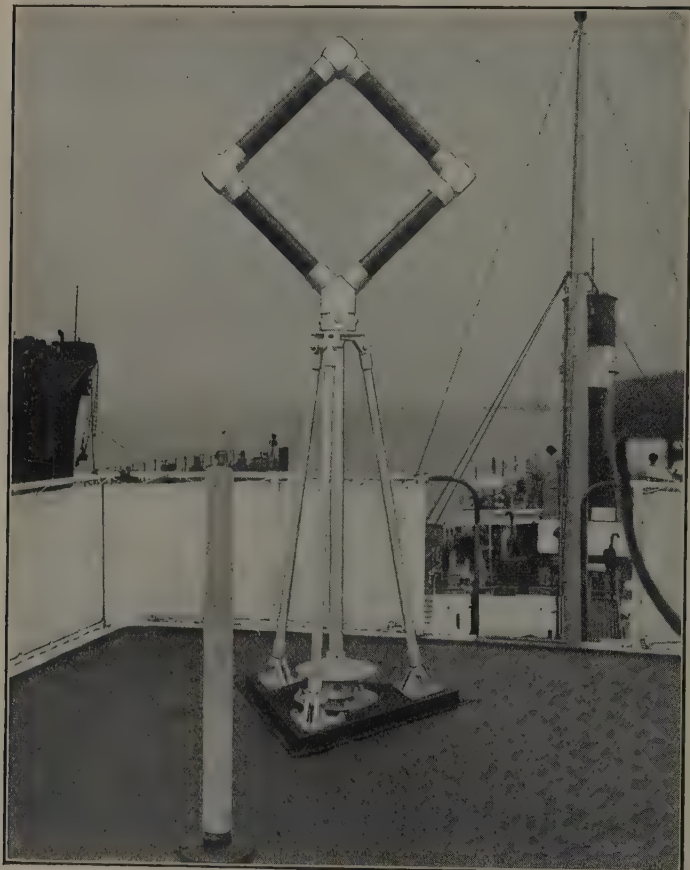


FIG. 214.—R.C.A. radio compass loop.

other tubes which are not quite so critical. In a good many cases this change will effect the desired result.

A short-circuited by-pass condenser may give endless trouble and is usually discovered by the rapid deterioration of the B battery. Further proof of this will be evidenced when the B

batteries are connected up and a spark is obtained. Should this be the case look for a short-circuited by-pass condenser.

Another prominent trouble encountered is a sort of *scratching* or *static* noise in the telephone. This is mostly due to the action

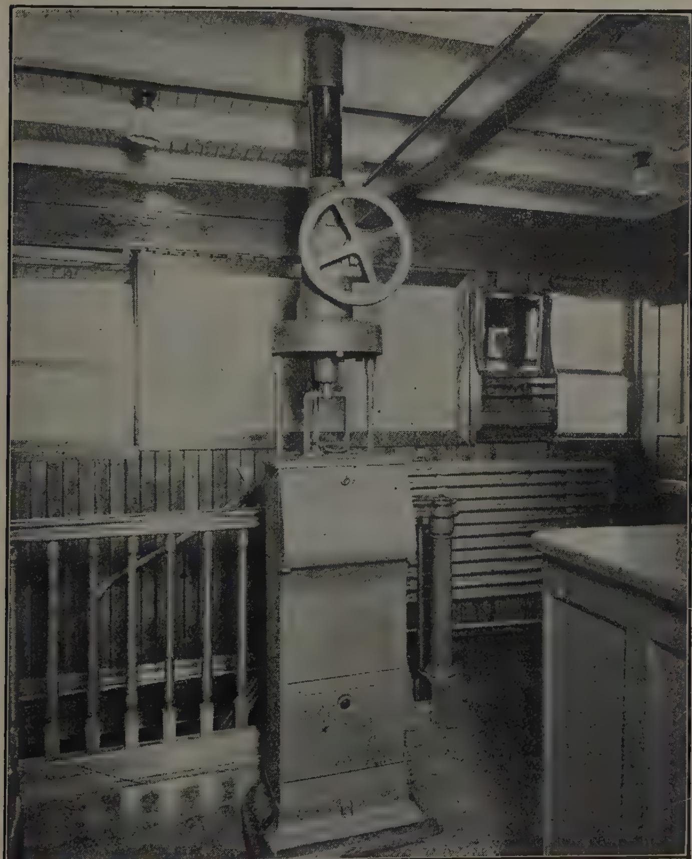


Fig. 215.—Chart-house installation of R.C.A. radio compass.

of the brush contacts upon the collector rings which lead from the loop to the receiver, and can be remedied by unscrewing the plate above the main compensator housing and thoroughly cleaning the rings with fine sandpaper and cloth.

Noises of the above nature may also be caused by corroded or loose battery connections, etc.

Additional Information.—When a vessel is in port and there are probabilities of the ship's power being shut off, it is advisable to

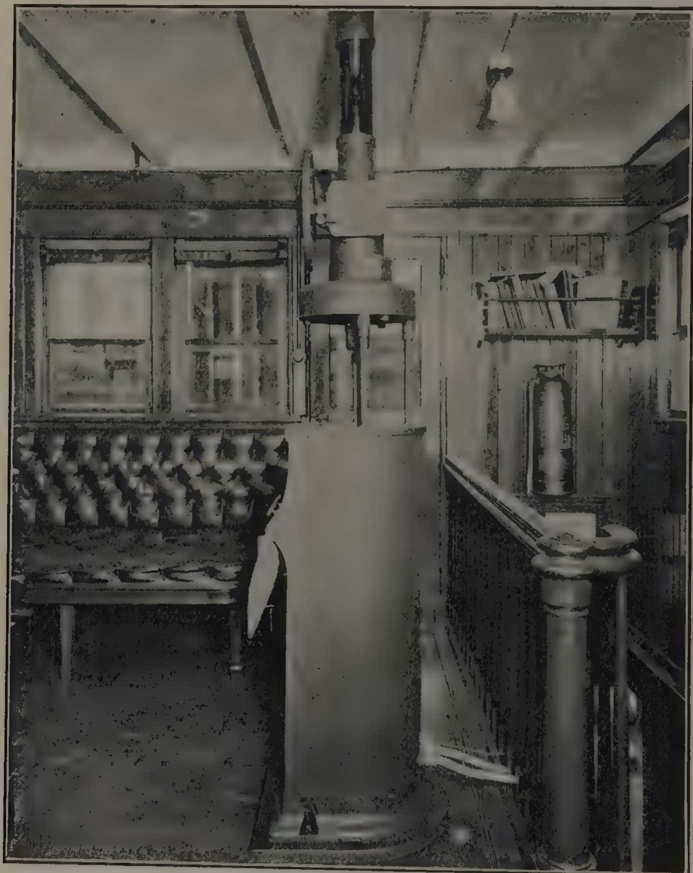


Fig. 216.—Chart-house installation of R.C.A. radio compass.

disconnect the filament battery, in the event of a polarity reversal when the power is again put on. It is recommended here that all operators should test their polarity before reconnecting, in order to avoid the possibility of ruining the storage battery. Serious consequences in a case of this kind may result.

Figures 214, 215, 216, and 217 show four views of the complete R.C.A. compass equipment.

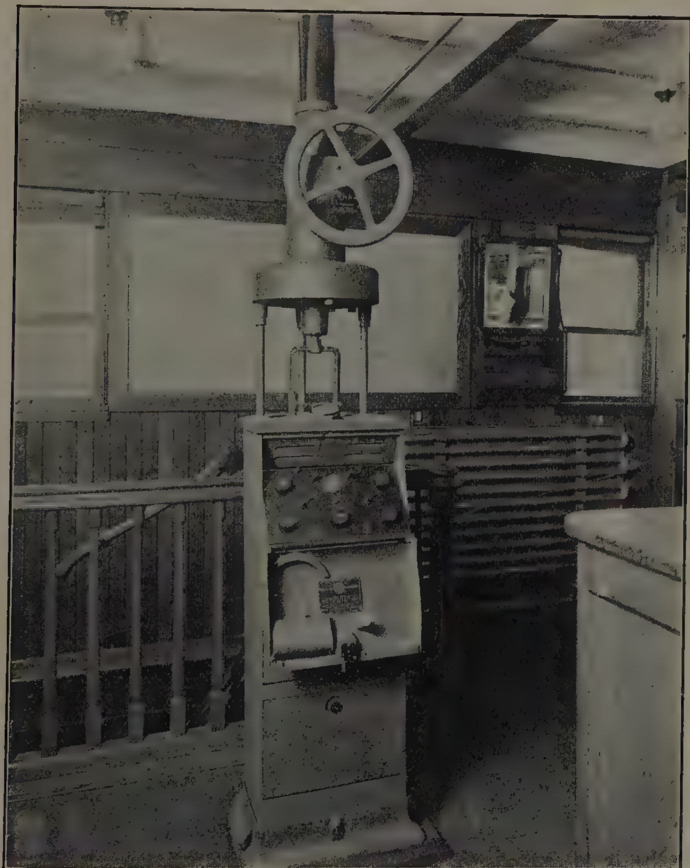


FIG. 217.—Chart-house installation of R.C.A. radio compass.

KOLSTER RADIO COMPASS FEDERAL TELEGRAPH COMPANY, TYPE AM3800

The theoretical function of the Radio Compass has been explained and will not, therefore, be treated again. The following paragraphs give a complete description of the operation of the Federal type of compass.

Description and Operation of the Kolster Radio Compass.—A complete diagram of the accessories and installation on shipboard of the Kolster radio compass is shown in Fig. 218.

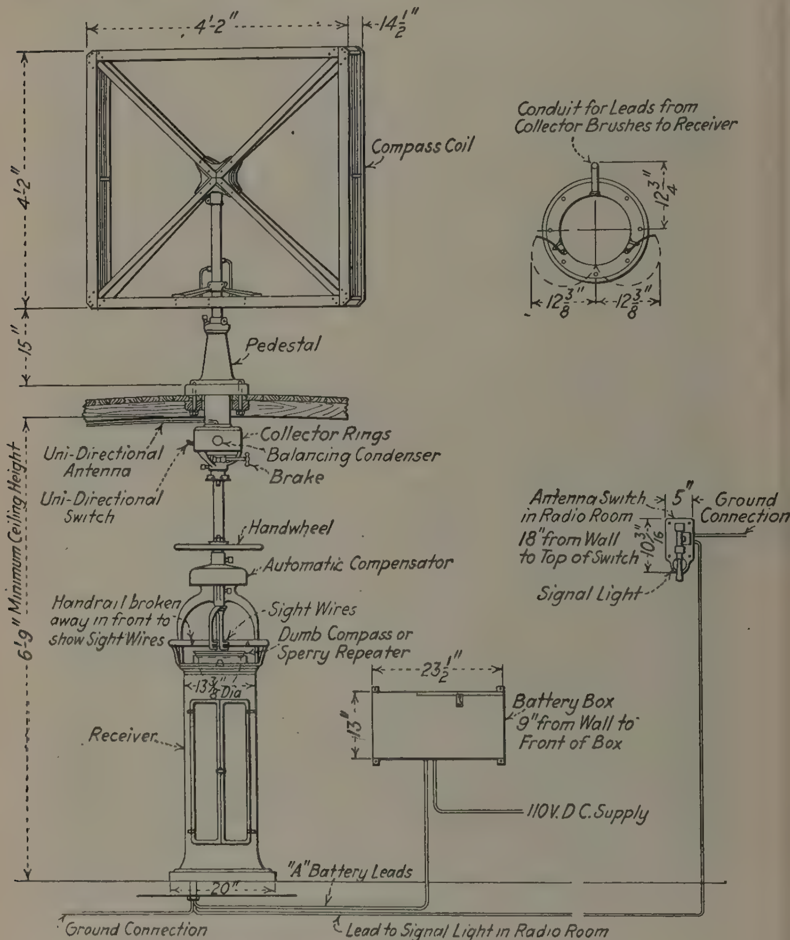


Fig. 218.—Kolster radio compass type AM3800.

The loop frame is about 4 ft. square by 15 in. wide and is wound with several turns of special radio frequency cable which forms the coil inductance. The loop frame is mounted edgewise upon a vertical shaft which is supported in a ball-bearing pedestal.

This pedestal may be mounted on the roof of either the chartroom or the pilot house, as shown in Fig. 224. The induced energy from the signal into the loop passes down through the shaft and makes connection with the radio receiver through two slip rings.

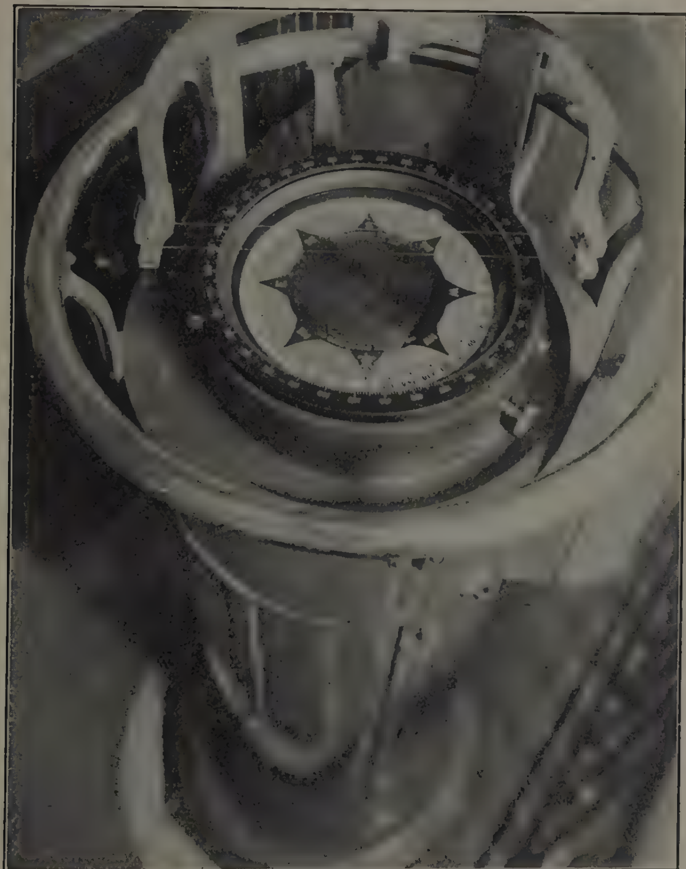


FIG. 219.—Kolster radio compass bowl.

The brush contact on these rings allows the current to pass from the loop into the radio receiver for detection. Incidentally, this brush contact allows the loop to be rotated about its vertical axis by means of a large hand wheel. At the extreme end of the shaft there is attached a pair of sight wires which travel directly

over a compass card or degree scale by which the angle between the station upon which the bearing is taken and the magnetic north, the true north or the ship's direction can be read directly.

Figure 219 shows the arrangement of these sight wires over the bowl of a compass. These sight wires are also fastened to a mechanical device known as an "automatic compensator." This device automatically corrects any error which might be caused by surrounding obstructions, such as the hull and riggings, which might be in the path of the incoming signals waves.

In all compass installations, the accuracy of degree reading may be affected by the *antenna effect* of the compass coil for the various positions in which the loop might be placed. This can be remedied by a balancing effect and thus result in an extremely sharp degree reading. This is accomplished by a device known as a "balancing condenser," which is mounted at the upper end of the shaft in the same casing with the collector rings, as illustrated in Fig. 218.

As the loop is rotated by means of the hand wheel, the incoming signals from a radio-beacon station will be heard with a maximum degree of intensity when the loop is pointing directly in the direction from which the waves are eminating. In order to obtain an accurate bearing, however, it will be necessary to rotate the loop so that it will be at right angles to the direction of the incoming waves, so that the signal will die out entirely. It is this position of silence or minimum intensity which is most critical and, therefore, indicates with a greater degree of accuracy the exact line of direction. Then by means of cross-bearings on two or more stations, or by several bearings from a single station with the distance logged between bearings, an extremely accurate position of the ship can be determined simply by triangulation with an accuracy which is equal to visual bearing on visible fixed objects.

The operation of the loop for obtaining bearings from one or two radio-beacon stations is extremely simple, but should it be desired to obtain the line of direction of another ship at sea, then it would be necessary, in order to obtain true direction, to unbalance the loop by increasing the antenna pick-up effect. This is accomplished by connecting a small antenna to one side of the loop by means of a switch, as shown in Fig. 218. Under normal conditions, this switch would be left open when taking a

bearing, but should true direction be desired the operator must close the switch and turn the loop to the position of the maximum signal, at which point the plane of the loop lies in the direction

FIG. 220.—Kolster radio compass, showing panel arrangement, type AM3800.

of the signaling station and points toward it as indicated by an index pointer which has been provided for that purpose.

The percentage of minimum with the Federal compass is guaranteed an accuracy of 2 per cent within 100 miles.

The Receiver.—The radio receiver is located directly beneath the compass, as shown in Fig. 220. It consists of three stages of

radio frequency amplification, detection, and two stages of audio frequency amplification, making six tubes in all.

These tubes are of the standard 201A type used for 6 volt storage-battery operation.

The wave-length range of this receiver covers a band of from 500 to 1,060 m., the complete range being covered by a single dial control.

The plate supply for the vacuum tube for this type of receiver consists of 90 volts of the standard dry B batteries. These are located beneath the receiver at the base of the compass stand.

The filament or A battery is a 6-volt Edison storage battery. It is contained within a wooden box which is usually mounted on the wall. The box also contains a jar of distilled water, a filling syringe, and a double-pole, double-throw snap switch, whereby the battery may be connected to either the receiver or to the ship's power for charging. The correct charging rate for this battery is fixed by a charging resistance also mounted within the box.

Practical Operation:

1. Put the telephone plug into the jack receptor on the panel.
2. Light the filaments by pulling out the filament button at the right of the panel.
3. Adjust the filament voltage to 5 volts as indicated on the filament voltmeter by adjusting the voltage regulator knob.
4. Set the wave selector dial to the desired wave length (this will be found to be at about three-fourths of the scale for the 1,000-m. radio-beacon stations).
5. Open the brake at the top of the shaft above the hand wheel.
6. Rotate the hand wheel until a maximum signal is obtained.
7. Decrease the signal strength by rotating loop at right angles to the direction of the incoming waves. A point of minimum signal should be found.
8. Adjust the balancing condenser until an extremely sharp *minima* is obtained.
9. If signals are too strong and the *minima* point is difficult to obtain, after the balancing condenser has been adjusted, decrease the signal intensity by adjusting the intensity regulator on the panel.
10. Having obtained a sharp *minima* or zero signal, look down over the sight wires so that one wire is directly beneath the other when only one wire can be seen. The degree reading beneath the apparent one wire will then give an accurate indication of the plane of the incoming wave. Thus by means of cross-bearing on two or more stations, or by several bearings on a

single station, the position of the ship may be easily determined by simple triangulation.

Note.—It is extremely important that the antenna switch and signal lights are in the proper position when bearings are being taken.

1. Antenna switch must be open when bearings are being taken.
2. The red light on the base of the switch and the green light on the radio receiver indicate that the antenna switch is open. If the green light is not lit on the panel the navigating officer will inform the radio operator to disconnect the antenna switch which immediately lights both the red and the green lights.

The radio operator will therefore cease operation during the period that his red light is lit.

KOLSTER RADIO COMPASS FEDERAL TELEGRAPH COMPANY TYPE AM4490 (A LATER MODEL)

Description and Operation.—A complete diagram of this type of Kolster radio compass is shown in Fig. 221. The loop in this type is of slightly different design than the one used in the previous model. The loop is completely enclosed within a circular housing in a manner such that it is entirely free to rotate without any retardation effect which might result under severe conditions of wind at sea. The micarta housing also protects the loop from any possible mechanical damage. Figure 222 shows a typical housing of this type.

The operating features of this model are identical with the previous one with the exception of various improvements in mechanical and receiver design.

One of the main additions is an improvement obtained by means of a visual indicator. This is one of the later developments of the Federal Telegraph Company.

With this method it is possible to obtain a bearing by noting the change in brilliancy in the glow of a special type of lamp containing an inert gas.

The function may be described briefly as follows: If the loop is rotated to a position where a maximum current is induced into it, it will be seen from previous explanations that this current will be a maximum if the loop is in the direct plane of an incoming wave; consequently, if the loop is at right angles to the direction

of the station a minimum of current will be induced into it. If the current induced into the loop is large enough it may actually be made to ionize the gas medium in the tube, which will result

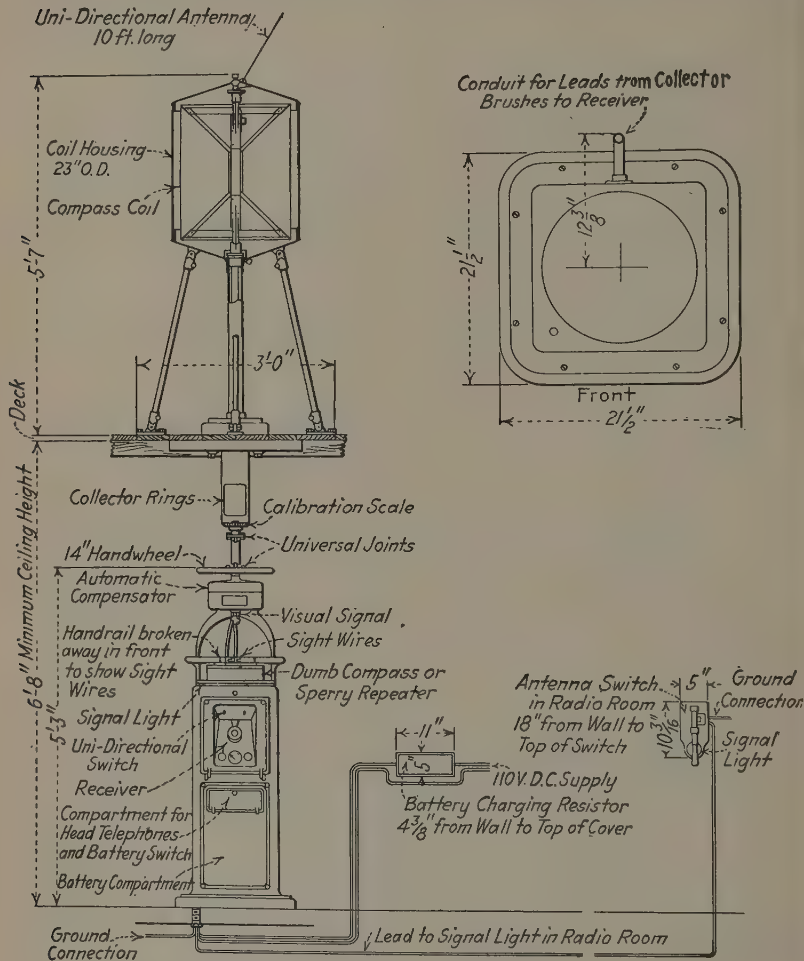


FIG. 221.—Kolster radio compass type AM4490 (a later model).

in a glow. Then, as the loop is rotated to a point where the minimum signal is induced into it, the lamp will not glow. Thus it will be seen that the lamp will cease to glow between two

readings of the sight wires, the mean of which will be the true bearing. It must be borne in mind, however, that the width of the compass sector over which the lamp is dark will depend on the strength of the transmitting station and also the distance from this station to the ship which is taking the bearing. It has

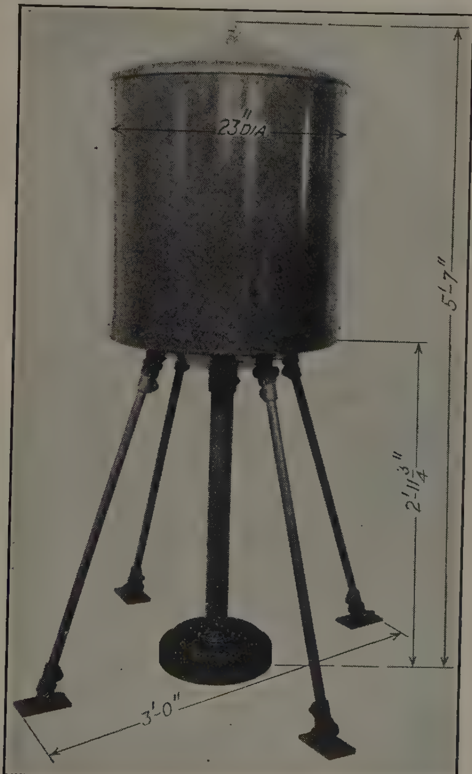


FIG. 222.—Kolster radio compass loop housing.

been found that a reading accurate to 2 deg. can usually be obtained over a distance of 25 miles.

There are several other decided advantages of this system over the audible system. For example, it is possible to rotate the loop to a point so that signal transmitted from either a land beacon or a mobile radio beacon installed on another ship will cause the lamp to light as soon as the vessel comes into a danger-

Fig. 223.—Kolster radio compass, type AM4490, showing panel.

ous position, thus making it possible by this means, to have the lamp placed in a conspicuous position whereby the navigator may observe approaching danger by occasionally glancing at the lamp, which would also be visible when glowing.

The Receiver.—The receiver in this type of compass as in Fig. 223 is an especially designed circuit to give a maximum of sensitivity and selectivity together with simplicity in operation. The tuning is accomplished by a single dial control. The receiver contains eight tubes and is connected in a manner which is equivalent to four stages of radio frequency amplification, detector, and two stages of audio amplification. The wave-length range of this receiver is from 550 to 1,050 m.

The A and B batteries for the tubes in this receiver are self-contained and are located beneath the receiver at the bottom of the binnacle. The A battery is of the 6-volt Edison type. The double-pole, double-throw snap switch is located within the telephone compartment directly beneath the receiver, by means of which the battery may be connected to either the receiver or the ship's power for charging.

Practical Operation.—The practical operation of this model is similar to the type AM3800, with the exception that the method of indication at *maximum* signal inten-

sity is by the sight method (glow lamp) instead of the audible method.

The panel arrangement is also the same so far as the number of controls are concerned. The switch, however, which connects the small antenna to one side of the loop, as mentioned in the AM-3800 model, instead of being at the top of the shaft, is located at the upper left-hand corner of the downward sloping panel with a filament switch at its right.

Federal Compass Troubles

Trouble	Probable Source
No signals received	Defective tube. Headset open or short-circuited. B battery open. Tube-socket spring bent or weak. Open transformer. Short-circuited condenser.
Nearby signals weak	Defective tube. A or B battery voltage low. Defective headset.
Sputtering noises	Loose connection in tube-socket springs. Defective A battery. Loose connection in snap switch in battery box or at battery lugs. Dirt on collector rings or brushes. Atmospheric disturbance. Sparking commutator of ships generator or motors. Induction from electric ozonator for purifying air.
Signal lamp does not light when antenna switch is open and radio compass receiver switch is closed.	One or both lamps burned out or loose connection in the sockets. Broken or grounded wire between radio compass and radio room.
Radio bearings incorrect	Steel cargo hoists not in same position as when compass was calibrated. Jumpers or clamps on stays have become loose. Insulators removed from stays. Wire log line hauled up in rigging. Radio antenna switch closed. Bearing being taken over a stretch of land. Sight wire frame bent or wire dissarranged. Compensator not properly adjusted to follow the calibration curve.

FEDERAL COMPASS TROUBLES—*Continued*

Trouble	Probable Source
Point of silence or minimum not sharply defined........	Balancing condenser not properly adjusted for a minimum when bearings are taken. Radio antenna switch closed. Signals weak. Ship alongside dock or metal structure. Insulation leakage in loop circuit at collector rings or brushes. Water or moisture in the stem of the conduit.
Receiver oscillates or howls.	Intensity regulator set too high. Defective radio frequency tube. Defective B battery. A battery voltage regulator set too low.

Questions

1. What is the purpose of the radio compass?
2. What is the meaning of bilateral and unilateral characteristics in radio compass work?
3. How does the radio compass operate theoretically?
4. Draw a diagram of a simple radio compass.
5. How would it be placed into operation?
6. How is a bearing obtained with the Radio Corporation of America type AG1382 radio compass?
7. What is meant by null point?
8. What type of receiver is used with the Radio Corporation of America compass?
9. What are some of the common troubles experienced with this receiver?
10. Describe the Federal-type AM3800 radio compass.
11. Describe the Federal-type AM4490 radio compass (later model).
12. What types of receivers are used with each model?
13. What may the antenna effect have upon the accuracy of the bearing? How can it be remedied?
14. Describe the practical operation of model AM4490.
15. What are some of the probable Federal compass troubles?

APPENDIX B

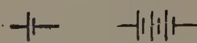
SYMBOLS

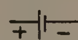
The symbols below arè reproduced by permission of The Institute of Radio Engineers.

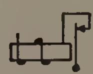
Ammeter 

Antenna or Aerial 

Arc 

Battery 

Battery (polarity indicated) 

Buzzer 

Coil Antenna 

Condenser, Fixed 

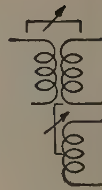
Còndenser, Shielded 

Condenser, Variable 

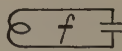
Condenser, Variable (with moving plate indicated) 

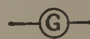
Counterpoise 

Coupler, Inductive (mutual inductor) 

Coupler, Inductive (with variable coupling)  

Crystal Detector 

Frequency Meter (wavemeter) 

Galvanometer 

Ground 

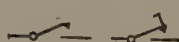
Inductor 

Inductor, Iron Core 

Inductor, Variable 

Inductor, Adjustable 

Jack 

Key 

Lightning Arrester 

Resistor 

Resistor, Variable 

Spark Gap, Non-synchronous	
Piezoelectric Crystal	
Spark Gap, Plain	
Spark Gap, Quenched	
Spark Gap, Synchronous	
Telephone Receiver	
Loud Speaker	
Telephone Transmitter (microphone)	
Thermo-element	
Transformer	
Vacuum Tube, Triode	
Vacuum Tube, Diode	
Voltmeter	
Wires, Joined	
Wires, Crossed not Joined	

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